Metallurgical Analysis of Chinese Coins at the British Museum

Edited by
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Front cover: Coin tree of brass *Guangxu zhongbao* coins,
Board of Revenue Mint, Beijing, China, Qing dynasty, *c.* AD 1905
(BM 1913-10-11-32).

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Contents

Preface

The aim of this publication is to bring together the results of metallurgical analysis on Chinese coins undertaken at the British Museum during the last 15 years. The largest project looked at the metal content of Chinese cash coins over a period of more than 2,000 years. Although the results of the survey were summarised and published (Bowman, Cowell and Cribb, 1989), full details of the survey and photographs of the coins tested are presented here for the first time, along with an introduction by Joe Cribb and comments by Michael Cowell.

Since then, smaller metallurgical projects have been undertaken at the British Museum, looking at specific questions, such as the iron content of Song dynasty coins, the brass content of Qing dynasty coins, and the question of metal supply for Qing dynasty coins. The results of these projects are brought together here for ease of reference, and are presented in chronological order of the material examined.

We would like to thank our co-authors Yvonne Shashoua, formerly of the British Museum, and Michael Wayman, Professor of Metallurgy at the University of Alberta in Edmonton, for their friendly co-operation, and the Royal Numismatic Society and the Historical Metallurgy Society for allowing us to reproduce the published articles here.

The analysis for the projects in this volume has been done at the British Museum, using coins from the British Museum collections. In the last decade, numismatists and scientists in China have also been looking at similar questions, using coins from archaeological sites. It is important that we share the results. Zhou Weirong's new book, *Chinese Coins: Alloy Composition and Metallurgical Research*, will be available soon, and we would like to thank him for agreeing to let us publish an English version of the introduction, postscript and contents pages of his book as an Appendix here.

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Introduction

Joe Cribb

For over 2,000 years from the 3rd century BC until the second decade of the 20th century, the main official form of currency in China was the standard copper alloy coin.[1] Known as *quan, qian* or *wen* in Chinese, and by its pidgin name *cash* in English, this coin was characterised by its shape, round with a square hole, by its design, an inscription, and by its method of manufacture, cast from copper alloy in a mould. The longevity of this coin positions it as an important index of change in metallurgical practice through China's history. The steady export of these coins from the 7th century to Eastern Turkestan, Mongolia, Japan, Korea, Vietnam, Indonesia, Malaysia, Thailand, India, the Persian Gulf, the Arabian Peninsula and East Africa, has also provided these regions with a supply of copper alloy.[2] Furthermore, in China and elsewhere these coins have been an important source of scrap metal for manufacturing utensils and images.

The purpose of the study on which this volume is based is to provide an overview of the use of copper alloys in the production of coins for more than 2,000 years, during which the cash dominated the currency systems of East Asia. The study of the copper alloy cash has also prompted examination of occasional issues of coins made from other base metals in China, including lead, zinc and iron.

The papers reprinted here represent a collaboration between the British Museum's Department of Coins and Medals and Department of Scientific Research (now part of the Department of Conservation, Documentation and Science). They set out the scientific principles and methods used in analysing and understanding the metals and alloys used in casting the coins. The papers focus on particular indications arising from the analyses, such as casting techniques, the introduction of brass using metallic zinc, the use of leaded bronzes, the import of copper from Japan and the medieval production of cast iron.

In September 1981, when the collaboration started, the decision was made to test at least two coins of each type (if available), to provide limited assurance of the result from individual coins. In some instances wider samples were tested, particularly to investigate specific points of interest. For periods when coins were issued with deliberately varying calligraphies, samples were chosen across the range of calligraphic styles to see if the function of the variation was to indicate metallurgical differences. In some instances contemporary issues from different mints or from different regions were analysed to see whether alloy standards were centralised.

The major results from this study are to be found in the papers presented here, but the results also suggest that other issues remain to be investigated arising from the full set of analyses. In one case, the comparison between Tang period coins made in China with those collected in Xinjiang (Chinese Central Asia), was made available to another scholar.[3] The results showed that the production of both specific local issues and versions of centrally issued coins took place in Xinjiang and a more heavily leaded bronze was used in casting them.

The appearance of the first of these papers coincided with a project by Professors Dai Zhiqiang and Zhou Weirong of the Chinese Numismatic Museum, Beijing and Fan Xiangxi, a colleague from Beijing Teachers' University, who conducted a parallel series of analyses. Their results have largely corroborated those presented here, while calling on a broader range of Chinese textual sources to improve the understanding of the significance of the results.[4] Their scientific methods were different: volumetric titration and atomic absorption spectrophotometry. The latter was also used by the British Museum Research Laboratory for some of its analyses, but X-ray fluorescence was the main method used.

The following are some general observations on the British Museum analyses, raising some issues which would benefit from further research and analyses being made.

Coins of the pre-Qin period (*c.* 350–221 BC)

Only round coins of the pre-Qin period were analysed at the British Museum, but their results are usefully compared with the analyses of knife- and hoe(spade)-shaped coins made by Dai and Zhou. The British Museum round coins show two different compositions: coins nos 1 and 2, inscribed *yuan*, are almost pure copper, but nos 3–6 are all made from the leaded bronze alloy which Dai and Zhou show was normally used to cast knife- and hoe-shaped coins.[5] The round coins with leaded bronze are, however, alloyed with less lead than the so-called *ming* knife coins of the Yan State with which they are usually associated. The Yan knife-shaped coins analysed by Dai and Zhou mostly contain 40–60% lead.

Han to Sui dynasties (206 BC – AD 618)

The Han period *banliang* coins represent three different issues, *c.* 200 BC (nos 11–14), *c.* 175 BC (nos 15–18) and *c.* 150 BC (nos 19–22). The first two issues were made with the same leaded bronze of inconsistent quality as the pre-Qin coins (nos 3–6), but mostly with a higher tin content, whereas the last issue is, like the *yuan* coins (nos 1–2), of almost pure copper. Both the *yuan* coins and the 150 BC *banliang* coins contain traces of lead, tin and iron, consistent with them being made from the first refining of copper ores, suggesting that they were probably made close to the mines from which the ore was extracted. A distinctive characteristic of these coins is that the small amount of iron in them renders the coins susceptible to a magnet.[6] A similar phenomenon has been observed in 1st century BC and 1st century AD coins from ancient Kashmir, probably because these were also made close to the sources of copper ores.[7]

Coins issued by Wang Mang show a similar leaded bronze alloy to the early Han *banliang* coins, but in most cases with a higher copper content (80–95%). The *huoquan* examples are of two varieties (distinguished by the treatment of the central hole). The two specimens with a dotted upper rim to the hole (nos 25 and 26) show a lower copper content (70–80%) than the other two (nos 23 and 24) with a rimmed hole (80–95%). This may indicate different mints or different dates of issue. The *daquan wushi* coins (nos 27–32) are close in alloy to the latter pair (nos 23 and 24) with higher copper content, even though their varied sizes suggest different dates of production. The coins inscribed *xiaoquan zhiyi* (nos 33 and 34) are of a lower copper content, like the dotted rim *huoquan* coins (nos 25 and 26).

Although the Western Han *wuzhu* coins (nos 35–38) show similar differentiation marks to the Wang Mang *huoquan* coins (nos 23–26) they all seem to be of a consistently high copper leaded bronze, like most of the Wang Mang coins tested. One *wuzhu* coin (no. 39) normally attributed to the Western Han because of its marked corners, however, shows a lower copper content more consistent with that of the Eastern Han *wuzhu* coins (nos 40–41) also with four projections, but on the back. The other two Eastern Han *wuzhu* coins show the same higher copper content as the Western Han coins. The variation of quality and markings on the coins suggests that the markings might have been added to indicate the change in quality of the alloy. More extensive sampling of the series would help to clarify the significance of this. The examples analysed by Zhou and Dai represent an early group of Western Han *wuzhu* issued *c.* 118 BC, which show a range (71–88%), which overlaps both the higher (80–95%) and the lower copper (70–80%) leaded bronzes as observed in the British Museum analyses, and a group of Wang Mang coins all made from the higher copper alloy (82–86%).

Two tiny versions of the *wuzhu* coinage, attributable to the late Western Han period show a widely disparate copper content. The varying quality of the two examples tested suggests that no. 45 has the higher copper content of the other Western Han wuzhu coins tested (nos. 35–38), but no. 44 is of such a low quality that it could be an unofficial copy of the period.

The coins of the local dynasties following the end of the Han period show a general adherence to the lower copper content leaded bronze of the Eastern Han period, with all specimens falling within, or close to, the range 70–80% copper.

Tang dynasty (AD 618–907)

Three groups of Tang coins have been analysed, all showing the same leaded bronze alloy of varying proportions as used earlier.

The first group are the typical *Kaiyuan tongbao* coins introduced at the beginning of the dynasty and continuing to be issued until its demise. These were selected to show the range of styles, additional marks and sizes. They show a lack of consistency in the copper content of the leaded bronze alloy used throughout the Tang period, with a range of 67–94%. The coins were selected in pairs, but even these show the same lack of consistency (nos 64 and 65: 67–94%; nos 68 and 69: 68–78%). A larger sample would show if the selected pieces are typical or exceptional. Two token coins (nos 76–77) issued in AD 666, when *Kaiyuan tongbao* coins were still in regular production, show copper contents in the higher part of the range of the *Kaiyuan tongbao* coins.

The second group come from the middle of the Tang period. A token issue, inscribed *Qianyuan zhongbao*, was introduced in AD 759 which went through various stages of reduction in weight. Remarkably, the largest examples tested (nos 78–80) are well below (36–52%) the normal range of copper content recorded for the early Tang issues. One example (no. 81) had the appearance of a brass copy and testing showed a significantly high zinc content, suggesting that it was probably made in the late Qing period (19th century) for collectors. The standard size tokens (nos 82–85) show two distinct copper contents. Three examples (nos 82, 83 and 85) have a consistent copper content in the range 65–68%, but the fourth piece (no. 84) has only 6.8% copper. This example was collected in Xinjiang by Rudolf Hoernle (1841–1918) and was probably made in that region. One of the good quality pieces (no. 85) was also collected in Xinjiang, but its copper content suggests that it was imported into the region from China. Examples showing two stages of reduction in size and weight of the standard token have been tested. Again they show two different ranges of copper content. Most of the examples are within the range 75–79%, slightly higher than the full size tokens. Two examples fall just below this (nos 92 and 93), with a range of 59–64% copper content. These have a smaller inscription than the others and are perhaps intentionally lower in quality. They also show a slightly higher iron content than the other examples. The last two examples (nos 94 and 95), which were collected in Xinjiang, have an even lower copper content (25–44%); they are also the smallest and lightest examples tested. Their low copper content, like that of no. 84, suggests that they were local products. This is supported by the *Dali yuanbao* coins (nos 96 and 97) which were issued in AD 769 only in Xinjiang. They also show the same lower copper content, with the tested examples, collected in the region, showing a range of 37–49%, well below the normal Tang period range.[8]

The third group (nos 98–143) are all issues of the late Tang period, a series of locally produced *Kaiyuan tongbao* coins from mints all over China, made in AD 845 following an order to produce coins. Although the coins were made at 23 different mints with a variety of versions of the *Kaiyuan tongbao* calligraphy, they show a remarkable consistency, with most examples within the range 70–80% copper.

Coins of the rebellion against the Tang in AD 759 (nos 144–145) have the same type of alloy as the standard token coins of the same period issued by the Tang emperor (nos 78–85).

Five dynasties – Ten Kingdoms period (AD 907–979)

The standard used in the late Tang, 70-80% copper in a leaded bronze of varying proportions, continued to be used in the period of fragmentation following the Tang dynasty. The 13 Southern Tang coins (nos 164–176) are mostly in the lower half of this range showing a tighter standard of 66–74%, while the 12 Former and Later Shu coins (nos 152–163) are mostly in the upper half with a standard of 75–83%. These differences suggest that slightly different standards for copper content were being used in different regions during this period.

In some regions lead or iron coins were issued, perhaps as a consequence of the many conflicts arising during the period leading to economic crises. Some lead coins of the Southern Han were tested and found to be of pure lead (nos 179–185).

Song, Jin and Yuan dynasties (AD 960–1368)

Leaded bronze continued to be the usual alloy used to make coins during the Song period, but in some areas iron coinage became normal, replacing bronze. This reflected an attempt to deal with the dwindling supply of copper as the export of coins became a large-scale activity. Some areas close to the northern Liao, Xi Xia and Jin dynasties used iron coinage as an attempt to create a barrier to the export of bronze coins into the territories of these dynasties.

Before about 1068 the copper content of the leaded bronze was mostly within the range 66–77%, but after that it fell slightly to a lower range 63–73%. In 1127 the Song dynasty lost northern China to the Jin dynasty and consequently lost some of its copper sources. This led to a continuing decline in standards with a widening range of copper content, most coins falling within the range 56–73%.

The analyses published by Dai and Zhou show a similar falling standard in the Song period with a range of 62–68% during the early Song period dropping to 50–60% after the loss of the northern territories, although their sample is much smaller (one coin for each of the 20 reign periods down to 1127 and 20 coins for 14 reign periods for the later period).

Some of the coins with Song dynasty reign period inscriptions are non-Chinese products, copied in Vietnam and Japan, where imported Chinese coins were in circulation. Numbers 245 and 246 are Vietnamese issues of a later date, showing a higher lead content than their Chinese prototypes.[9] Numbers 214 and 215 can also be attributed to Vietnam and have a lead content in the upper range of that of the Chinese issues, but their relatively low tin content suggests that they might not be issued in the same context as nos 245 and 246.[10] Numbers 311, 312, 315, 316, and 349–351 are probably Japanese products.[11] The first four all show a much lower tin content than their Chinese prototypes, but the last three are well within the normal range of the alloy of their Chinese prototype (except the high iron content of no. 349).

Two Jin dynasty (nos 412 and 413) and four Yuan dynasty coins (nos 415–418) were tested and all showed a higher copper content than the Song period coins, with a range of 71–83%.

Ming dynasty (AD 1368–1644)

The higher standard used by the Yuan dynasty seems to have been maintained by the early Ming emperors, but at first with a narrower range 70–78%, then rising to a range of 70–87% in the Hongzhi reign period (issued 1503-5). The coins of the Hongzhi reign period (nos 434–452) cannot be arranged chronologically, but the variations observed in quality could represent a changing standard. There is also an increased amount of zinc noticeable in the coins, with half of them showing above 1%. Two *Hongzhi tongbao* coins (nos 451 and 452) show an even higher zinc content, sufficient to suggest that the zinc was intentionally present. The work of Dai and Zhou has demonstrated that the early use of zinc in coinage used the cementation method, i.e. adding zinc ore to molten copper. In the case of these two coins it seems to have been added to the usual leaded bronze alloy. The copper, tin and lead are proportionately reduced by the addition of zinc, so that the copper content is in the range 66–69%.

The next issue of coins after 1503 was delayed until the Jiajing reign period (1527–1570). The use of zinc ore in coin production now became normal. Before the Wanli reign period (1576–1621), the zinc ore was normally added to the usual leaded bronze alloy, but during that reign some coins show so little tin (nos 465, 469 and 470) that the alloy can be considered to be brass. The amount of zinc also increased during the same period with a range of 7–33%. The high levels of zinc suggested to Cowell that zinc metal was being added to the alloy, but Dai and Zhou have shown from textual sources that zinc ore was being added until 1621.[12] After that date, tin levels are consistently below 1% and zinc levels rise in some cases to 40% as zinc was now being added to the alloy in metallic form.

Qing dynasty (AD 1644–1911)

The brass alloys of the Qing period have been discussed at length in the papers in this volume and by Hartill.[13] It is interesting to note the low zinc coins of the Yunnan mint before 1722. Yunnan was a main source of copper for the Qing dynasty and therefore seems to have made less use of zinc before it complied to the official standard being used in Beijing.

Notes

1 For a detailed account of Chinese coinage from its origins to the 20th century, see Peng Xinwei, *Zhongguo Huobi Shi* (Shanghai, 3rd edn, 1965), also trans. into English by E. Kaplan, *A Monetary History of China*, 2 vols (Bellingham WA, 1994).

2 See J. Cribb and D. Potts, 'Chinese coin finds from Arabia and the Arabian Gulf', *Arabian Archaeology and Epigraphy* (1996), 108–18; and J. Cribb, 'Chinese coin finds from South India and Sri Lanka', in K.K. Maheshwari and B. Rath (eds), *Numismatic Panorama, Essays in Memory of late Shri S. M. Shukla* (New Delhi, 1996), 253–69.

3 See N. Rhodes, 'Tang dynasty coins made in Xinjiang', in K. Tanabe, J. Cribb and H. Wang (eds), *Studies in Silk Road Coins and Culture* (Kamakura, 1997), 181–86.

4 See Dai Zhiqiang and Zhou Weirong, 'Studies in the alloy composition of past dynasties copper coins in China', in M. Hoc (ed.), *Proceedings of the XIth International Numismatic Congress, Brussels, 1991* (Louvain-la-Neuve, 1993), vol. 2, 311–24; Zhou Weirong and Fan Xiangxi, 'A study on the development of brass for coinage in China', *Bulletin of the Metals Museum* (Aoba, Sendai, Japan,1993), vol. 20, II, 35–45.

5 Dai Zhiqiang and Zhou Weirong, 'Studies'.

6 Cowell provided me with this explanation of the magnetic responsiveness of the impure copper used to make these coins.

7 B.K. Tanner, D.W. MacDowall, I.B. MacCormack and R.L. Smith, 'Ferromagnetism in ancient copper-based coinage', *Nature* 280 (1979), 46–48, based on similar magnetic responsiveness in Kushan coins originally observed by the late John Nisbet.

8 Rhodes, 'Tang dynasty coins'.

9 Nos 245 and 246 have the stylistic (small seal script) and casting technique (thin flan with broad rims on reverse) attributes of Vietnamese copies of Chinese coins. Parallels to them can be seen in F. Thierry, *Catalogue des monnaies vietnamiennes* (Paris, 1987), no. 105, and, Miura Gosen, *Annan Senpu*, (Catalogue of Vietnamese Coins), 3 vols (Tokyo, 1963), vol. 1, 81, no. 2 and 86, no. 4.

10 Nos 214 and 215 are attributed to Vietnam by Thierry, *Catalogue*, no. 1129, and Miura, *Annan Senpu*, vol. 1, 20, no. 3. Thierry identifies them as Vietnamese copies of Japanese copies of Chinese coins. The Japanese prototypes were made in Nagasaki *c.* 1659–1685.

11 Nos 311, 312, 315, 316 and 349–351 belong to the series of Japanese issues made in imitation of Chinese coins. Nos 311, 312 and 315 are attributed to the mint of Nagasaki 1659–1685, Japan by the Bank of Japan, Research Department, *Zuroku Nihon no Kahei* (Illustrated Japanese Money), (Tokyo, 1972), vol. 4, no. 313. Nos 315 and 316 and 349–351 are earlier privately minted imitations in the series known by Japanese scholars as *bita-sen* and *shima-sen*. Each example of *bita-sen* and *shima-sen* series is different, so it is not possible to refer to exact parallels, but examples of the series are to be found in Bank of Japan, *Zuroku Nihon no Kahei*, vol. 1, *bita-sen* nos 354–445, *shima-sen* nos 446–538.

12 Dai and Zhou were able to dispute Cowell's original interpretation of the evidence relating to the introduction of zinc; see 'Studies'. Cowell argued for the use of metallic zinc from the beginning of brass coinage in China, but Dai and Zhou were able to show, both from texts and the variation of trace elements that Chinese brass was initially made using zinc ore and only later was metallic zinc used.

13 See D. Hartill, *Qing Cash,* Royal Numismatic Society Special Publication 37 (London, 2003).

Two Thousand Years of Coinage in China: An Analytical Survey

Sheridan Bowman, Michael Cowell and Joe Cribb

Introduction

The primary aim of this project was to provide an analytical survey of dated copper-based Chinese cast metalwork. The potential of coinage for this purpose is obvious and, in the case of China, made particularly opportune by the long tradition of manufacture of the copper-alloy cash coin. For almost two millenia the Chinese used this copper-based unit as virtually their only official coinage for day-to-day use. For much of this time the style and method of production of the cash remained essentially unchanged.[1] Unlike the majority of Western coinages it was cast in its final form, instead of being struck, and this practice continued right up to the early 20th century.

The production methods used for cash manufacture were very conservative. We have a full account of the 17th century practice,[2] but much the same process had been used since the Han dynasty (2nd century BC). The coins were cast in large numbers in batches in two-piece moulds arranged vertically. Moulds were prepared from fine sand re-inforced with an organic binder and contained within a wooden box. A pattern of 50-100 'mother cash' (either individually made or identical copies of a single master cash) were pressed lightly into the surface and then a second mould box was placed face down on top. An impression was thus taken of both sides of the mother cash pattern. The mould boxes were then turned over and separated so that the mother cash remained on the lower mould surface. A fresh mould box was then laid on this and again the pair turned and separated. In this way a series of two-piece moulds were obtained. After clearing channels between the coin impressions and making a central runnel, the boxes were fixed together in pairs and, following a preliminary firing, metal was poured in. The result was a 'cash tree' from which the coins were separated and subsequently cleaned up. A few fragmentary and complete cash trees have survived. The one illustrated here (**Fig. 1 see cover**) although dating from the mid-19th century is typical of earlier examples.

In principle, the intention of this analytical survey was that the coins should merely provide a convenient dated series of metalwork. However, it has also been possible to use the analytical data to corroborate the numismatic study of the series, particularly the chronology of some of the later issues. There have been several recent analytical studies including Chinese coins,[3] but they were restricted to comparatively short periods and no complete survey can be established from them.

There are a number of reasons why such a dated survey of metalwork would be of interest. One of these concerns the possible early use of more exotic metals and alloys some of which are alluded to in Chinese texts. For example, it has been suggested that the early use of cupro-nickel by the Indo-Greeks in Bactria during the 2nd century BC was initiated by trade contacts with the Chinese,[4] although this was refuted by Cammann.[5] A more recent technical study of the Bactrian coinage provides data that are also opposed to the introduction of the alloy from China.[6] Nevertheless, one of the reasons for suggesting a Chinese origin for cupro-nickel was the availability of suitable ores in south-west China. These were certainly exploited from the 16th century AD for the manufacture of 'paktong', a copper-nickel-zinc alloy, which was later widely copied in the west. Chinese texts suggest that it was known much earlier than this and possibly used for the casting of coins.[7] However, there are no verifiable analyses to support this. Clearly, it would be useful for a more systematic survey of the coinage to establish whether or not nickel was a substantial component of typical early Chinese copper alloys.

Further interest centres around the manufacture of metallic zinc by the Chinese. Needham has traced references to alloys that are presumed to contain zinc back to the 2nd century BC with retrospective accounts possibly referring to the individual metal in the 9th or 10th century AD.[8] However, there is no definite evidence for the isolation of metallic zinc by the Chinese until the early 17th century AD.[9] There are reported analyses of 2nd century BC Han dynasty coins containing several percent of zinc,[10] but the authenticity of these coins cannot now be confirmed. Although the concentration of zinc in these coins is no higher than that which could be achieved by the cementation process, this would be early evidence for the use of the process in the East and worthy of further investigation. The zinc coins analysed by Leeds which were thought to have been minted from the 15th century onwards are now believed to be oriental imitations made outside China in the 17th century at the earliest and possibly the 18th or 19th century.[11] During the late Ming and Qing dynasties there is well documented use of brass for the cash coinage but it is not clear to what extent cementation brass and metallic zinc contributed towards its manufacture. It would be of interest to know precisely when the introduction of brass took place and if it is possible to identify the earliest use of metallic zinc in its formulation.

Finally, a systematic survey of dated Chinese metalwork, not generally available in the West, would be useful information on the typical composition of casting alloys. This is not to imply that a database of coin analyses could be used to 'date' other Chinese metalwork but it would provide a useful framework for comparative studies.

Analytical techniques

Obviously, for a meaningful survey over such a long period of time, a large number of analyses are required to ensure that the data are representative. Since, in the first instance, the major alloying components were of principal interest rather than trace elements a rapid technique was required with moderate sensitivity. X-ray fluorescence (XRF) was therefore used as the principal analytical technique for all the coins but atomic absorption was subsequently applied to selected pieces to support the XRF data and extend the range of elements quantified. A Link Systems model 290 XRF spectrometer was used with a tungsten-target X-ray tube operated at 40 kV. A suitable area on the rim of each coin was normally selected for analysis and either scraped with a scalpel or abraded with silicon carbide paper to remove surface deposits of corrosion. Copper, tin, zinc, iron and lead were quantified in all coins and a selection were also analysed for nickel, antimony, silver and arsenic. The atomic absorption (AAS) analyses were carried out using a Pye Unicam SP9 spectrometer following the procedure described by Hughes *et al.* for copper-based alloys.[12] Fourteen major, minor and trace elements were quantified. Samples for AAS were taken by drilling into the edge of each coin with a 0.75mm drill bit and removing about 10mg of metal.

The limitations of XRF for the surface analysis of copper-based, particularly leaded, alloys have been noted,[13] and segregation of lead in Chinese coins has been found by Sano and Tominaga.[14] It was expected therefore that the accuracy of the results using this procedure would be compromised somewhat by inhomogeneities of the alloy. Replicate analysis and comparisons between XRF and AAS results on typical, not heavily corroded, coins indicate that the lead concentration will be subject to the greatest errors, typically ±10–15% relative as opposed to 5–10% relative for tin and zinc. This variation is less than the differences found between some of the coin groups and was considered acceptable for the purposes of this survey.

Results

General trends

About 550 coins have been analysed in this survey covering a period from the Zhou dynasty, the 3rd century BC, to the end of the Qing dynasty in the late 19th century AD. The coins were selected to provide as representative a spread of dates as possible. However, there are some periods when issues of coinage were severely restricted or curtailed completely, for example during parts of the 14th and 15th centuries, so that a complete coverage was not possible. During the period surveyed a number of mints were in operation throughout China which may not have always adhered to central minting policy. The investigation of possible regional variations in composition has yet to be examined however since the majority of the later coins included in the survey were selected from those attributed to or representative of the central mint at Beijing.

The results show that, in general, issues before the 16th century are leaded bronze whereas subsequently they are brass. The general trends in the composition of the bronze coins are summarised in **Figures 2 and 3** which display the average typical concentrations of lead and tin in the alloy (with bars indicating 1 standard deviation) for periods of a century or individual dynasties. It can be seen that for much of the period covered the coinage is heavily leaded bronze which is of course particularly suitable for cast metalwork. The lead content is typically in the range 10–40% and the tin content ranges up to about 16%. Although there are comparatively wide ranges in composition for coins issued over short periods, when these are averaged, some longer term trends become apparent. For example, prior to the end of the Tang dynasty in the 9th century AD there is a progressive increase in the amount of tin in the alloy but the lead content is rather erratic. After the Tang dynasty the overall trend is for the tin content to decline, except for one or two discontinuities. It is noticeable that during this period the trend in lead content is the oposite of that for tin, with the lead increasing at the expense of the tin and the copper. The progressive increase in the lead content may be related to the state of the Chinese economy because by adding lead there would be a saving in the more expensive copper and tin. It is significant that during the Song dynasty, when there are known to have been shortages of copper and greater demands on the coinage,[15] the increase in the lead content is most pronounced.

The survey has also identified the point at which the coinage alloy changed from leaded bronze to brass, or more accurately a quaternary alloy containing substantial amounts of zinc, tin and lead. This change occurred during the years 1503 to 1505. The compositions of the coins during this critical phase are listed below in **Table 1** together with the subsequent issues to 1566. Unfortunately only date ranges can be given for some of the coins in this table because the issues cannot as yet be more precisely dated. In addition, no coins seem to have been issued in the period 1505 to 1527 probably because of attempts to introduce a paper currency.[16]

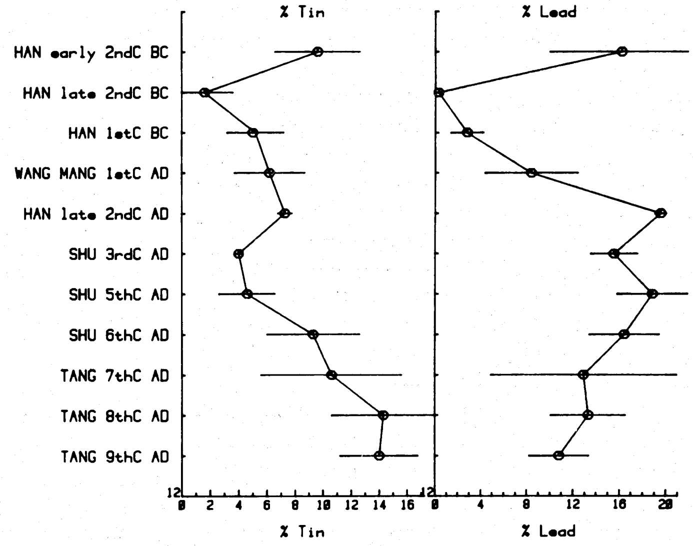
The results in **Table 1** have been ordered to group together the brass issues and also to indicate an apparent trend in the composition of the bronze issues. The latter have been ordered by decreasing lead to tin ratio but the numismatic significance of this has yet to be investigated. Out of the 19 coins analysed that were issued during 1503–05, 2 (550 and 548) contain substantial amounts of zinc whereas most of the remainder are leaded bronze. All the coins examined with dates after 1527 are made of brass. The complete establishment of brass over leaded bronze for the cash coinage by 1527 is in accordance with near contemporary records such as those by Gu Ziyu [Ku Tsu-yu] in 1667, who notes that brass coins were used from 1520 onwards.[17]

Table 1 Composition of coins issued during the transition from bronze to brass

No.	Table no.	Date	%Cu	%Sn	%Pb	%Zn
539*	441	1503-5	80	3.7	15.7	0.2
543*	445	1503-5	69	6.7	23.0	<0.01
549*	452	1503-5	77	5.0	17.2	<0.1
541*	443	1503-5	74	8.5	16.2	<0.01
547*	449	1503-5	72	9.3	17.8	0.1
426	437	1503-5	79	7.6	12.4	0.5
536*	438	1503-5	79	7.7	11.6	<0.96
538*	440	1503-5	74	10.6	14.8	<0.01
427*	436	1503-5	77	10.1	11.7	<0.1
542*	444	1503-5	81	10.0	7.0	1.6
544*	446	1503-5	82	10.7	6.8	1.2
546*	448	1503-5	84	10.8	4.9	1.0
21	435	1503-5	87	8.5	3.7	0.4
545*	446	1503-5	84	10.9	4.1	1.3
22*	434	1503-5	85	9.8	2.8	1.2
540*	442	1503-5	85	10.0	2.8	1.7
537	439	1503-5	82	16.0	0.6	0.7
550	451	1503-5	66	7.4	10.9	16.2
548*	450	1503-5	69	7.8	9.6	13.3
430*	458	1527-66	82	3.2	0.8	12.5
429	456	1527-66	69	7.4	8.5	13.0
431*	457	1527-66	81	4.0	0.7	13.5
433	459	1527-66	70	5.5	7.2	16.0
428	455	1527-66	60	7.5	14.4	16.4
432	460	1527-66	70	5.5	6.5	17.4
20*	454	1527-66	69	7.4	5.2	17.8
19	453	1527-66	63	6.9	7.0	22.7

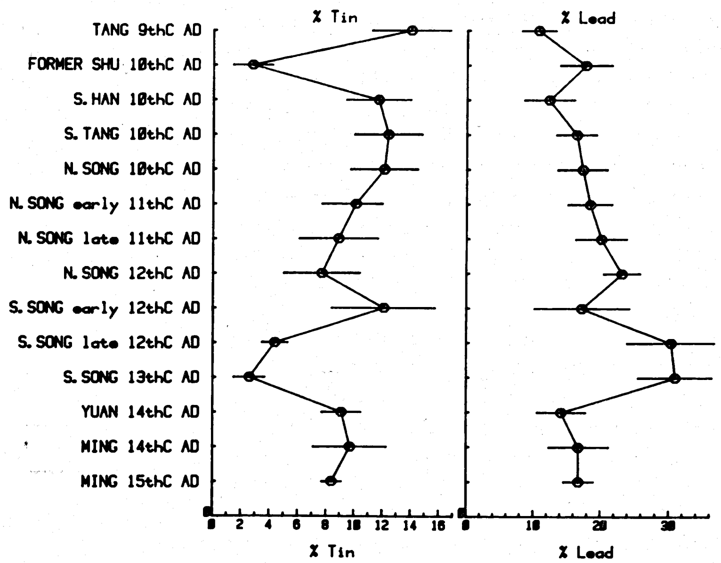
* Analyses by AAS, remainder by XRF

Figure 2



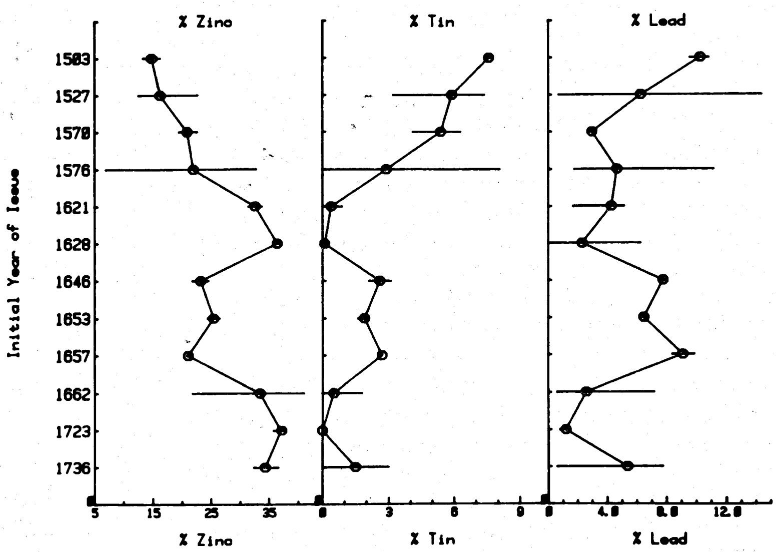
Bronze issues before the 10th century

Figure 3



Bronze issues after the 9th century

Figure 4



Brass issues from 1503 to 1736

Prior to the 16th century zinc occurs only as a trace component of the alloy, generally less than 1%. This is a concentration which could have arisen through fortuitous association with copper or lead ores. The few exceptions proved on detailed examination to be of uncertain authenticity because of incorrect style, artificial patination or absence of internal corrosion.

The nickel contents were found to be similarly low and none was greater than 0.5%. Certainly no early cupro-nickel was identified and even during the late Ming and Qing dynasties, when paktong was definitely being manufactured, nickel was never other than a trace contaminant of the coinage.

Brass coinage

The primary source of contemporary information on the manufacture of the Chinese brass coinage is the *Tian gong kai wu* [*T'ien-kung K'ai-wu*] written about 1637.[18] This gives precise details of the alloy used for the coinage, the method of casting and the preparation of the coins afterwards. The procedure referred to speaks of six or seven parts of copper alloyed with three or four parts of zinc, noting that about a quarter of the zinc is usually lost through vaporisation. Zinc was then regarded as a very cheap metal known as *wu qian* [*wo chienn*] or poor lead and took the place of lead in effectively reducing the amount of copper in the alloy. In consequence, contemporary forgeries were reported to contain the most zinc with up to 50% of the metal. Clearly metallic zinc was available in the East at this time in substantial quantities and it is well known to have been exported to Europe at the beginning of the 17th century.[19] In fact, the current results show that the brass coinage in China can definitely be traced back over 100 years before this. What indication is there for the use of metallic zinc, as opposed to cementation brass, over this period? As we will show, the analytical data provide strong evidence for the availability of metallic zinc in China from the first quarter of the 16th century.

The main alloy composition of the brass coins issued from the 16th century to mid-18th century are summarised in **Figure 4** by the means and ranges for zinc, tin and lead. This shows that the zinc content was initially only about 13–16% but, apart from some fluctuations, soon reached over 20%, and then by the early 17th century was 30–40%, which corresponds to the contemporary accounts. After the early 17th century the zinc content is occasionally reduced but not, it seems, below 20%. The wide, and apparently random, range in the zinc concentration over certain periods has some numismatic and historical significance which will not be explored in this paper. In addition to zinc the alloy also contained, at various times, substantial amounts of tin and lead, often totally 15–20%, whose concentrations are usually inversely correlated with the zinc. The presence of these metals is almost certainly connected with the use of re-cycled scrap, the possible inclusion of which is mentioned by Song Yingxing [Sung Ying-Hsing].[20] In this context, it is significant that the tin and lead concentrations are highest in the earliest brass issues, with their relative proportions being similar to that in the near contemporary leaded bronze coins (see also **Table 1**). There would have been substantial amounts of earlier leaded bronze coinage available at that time and it would have been uneconomical to have refined this in order to extract the more valuable copper and tin components.

The concentrations of tin and lead in the early brass coins suggests that at least half of the metal used derived from re-cycled bronze. It may be conjectured that the zinc in these same coins was introduced via cementation brass which could have had a maximum zinc concentration in the range 28–33%. However, after dilution with at least an equal weight of scrap bronze (in some cases perhaps twice as much), the zinc concentration of the final alloy could not then be as high as that actually found in most of the coins. Hence, it seems more likely to the authors that zinc metal was added to the alloy in appropriate quantities and this applies even to the earliest brass issues in the period 1503–05. There may also be some historical evidence for the addition of zinc in that a different metal (described as 'good' or 'superior tin') was added to some of the issues of the Hongzhi period (1488–1505) in the year 1505,[21] which is precisely the date of the first brass issues discovered here. If correctly interpreted, the original reference indicates that the amount of zinc added would have been about 12.5% which is similar to that found in the coins.

Summary

This survey has shown that the Chinese cash was usually manufactured from leaded bronze until the 16th century. Then, sometime during the period 1503–05, brass coinage was introduced, perhaps alongside that of bronze, until from 1527 onwards all subsequent issues were made of brass. The composition of these brass issues indicates that metallic zinc was used in their manufacture, rather than cementation brass, and hence that zinc metal was available to the Chinese early in the 16th century. Whether this was manufactured in China or imported, perhaps from India, cannot be determined from these data but certainly it must have been available in considerable quantities. The composition of the coinage provides no evidence of early brass production using the cementation process although this does not guarantee that it was not used for other metalwork. Indeed, before the brass coinage was introduced, there is abundant evidence of brass of probable cementation origin being used for statuary metalwork in China.[22]

[First published in *The Journal of the Historical Metallurgy Society* 23 (1989), 25–30.]

Notes

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Comments by Michael Cowell (2003)

The analytical project carried out in 1989, which included some 550 cash coins, was the most extensive analytical survey of Chinese copper-alloy coinage then published in the West. Prior to that, many analyses had been published in China and Japan, but these did not cover the complete period surveyed here.[1] However, at about the same time, and subsequently, there were many more analyses of this coinage being carried out in China, particularly by Zhou Weirong and colleagues,[2] that covered a similar period; their results are essentially compatible with ours.

The primary objective of the British Museum project was to provide analyses of representative coins over most of the period of cash production, thereby providing a general database of Chinese cast copper-based metal composition. It was intended that this could be used for comparison with other cast metalwork, such as statuary, and allowed periods of significant composition change to be identified for more detailed investigation, such as the introduction of zinc-containing alloys. To carry out the survey in a reasonable time, a relatively rapid technique was used for the majority of the analyses, X-ray fluorescence (XRF).[3] Even though areas on most of the coins were prepared to remove surface corrosion, the accuracy of this method is less good than those requiring a sample to be removed, such as atomic absorption spectrometry (AAS); the latter method was applied to some of the coins. Preliminary tests had indicated accuracies within the range ±10–15% relative for lead and ±5–10% for tin and zinc. Errors are likely to be highest for lead as this element forms a separate phase in the alloy. Subsequently, further comparisons between the XRF analyses and AAS analyses on drilled samples from the coins has indicated that the errors in the lead content may be somewhat higher at ±20–25% relative in a few cases and for tin up to ±15–20%, particularly where there is extensive surface corrosion. Therefore any interpretation of the XRF analysis data on the individual coins published here must take this accuracy into account. As noted above, the XRF project was intended as a preliminary survey that could be followed up by accurate analysis of parts of the series, by AAS or inductively-coupled spectrometry (ICPAES), where interesting trends in composition were found. This was the case with the Ming and Qing dynasty coins where the change from bronze to brass was investigated further, together with aspects of brass manufacture and imports of copper.[4]

Notes

1 For example, Dai Zhiqiang and Zhou Weirong, 'Study of the alloy composition of more than two thousand years of Chinese coins (5th c. BC to 20th c. AD)', *Journal of the Historical Metallurgical Society* 26, no. 2 (1992), 45–55. Zhao Kuanghua, Wang Weiping, Hua Jueming, Zhang Hongli, 'An analysis of the chemical composition of Northern Song bronze coins and a tentative inquiry into the quality of *dantong* in Song dynasty', *Studies in the History of Natural Sciences* 1986(5), 321–30. Yuji Sano, Kenji Notsu and Takeshi Tominaga 'Studies on chemical composition of ancient coins by multivariate analysis', *Scientific Papers on Japanese Antiquities and Art Crafts* 28 (1983), 44–58.
2 For example, Dai Zhiqiang and Zhou Weirong, 'Study of the metal composition'.
3 M. Cowell and H. Wang, 'Metal supply for the metropolitan coinage of the Kangxi period (1662–1721)', *Numismatic Chronicle* 158 (1998), 185–96.
4 M.R. Cowell, J. Cribb, S.G.E. Bowman and Y. Shashoua, 'The Chinese cash: composition and production', in M.M. Archibald and M.R. Cowell (eds), *Metallurgy in Numismatics 3* (Royal Numismatic Society, London, 1993), 185–96. Cowell and Wang, 'Metal supply'.

Notes to the Metallurgical Tables

No.
The coins are numbered individually on the plates.

British Museum registration numbers
As far as possible, coins were selected from established collections within the Department of Coins and Medals, British Museum. The registration numbers usually follow the format *year-month-group-item*. In this way, the registration number 1883-8-2-86 can be interpreted as the 86th item in the 2nd group acquired in the 8th month (August) of the year 1883. The registration numbers also indicate the provenance of the coins:

1847-11-9	Lieut. Forbes
1870-5-7	Dr Wilhelm Freudenthal (d.1883)
1882-6-1	Hosea Ballou Morse (1855–1934)
1883-7-1	Hosea Ballou Morse (1855–1934)
1883-8-2	Consul Christopher Gardner (1842–1914)
1884-5-11	H. Wills (ex-Kutsuki Masatsuna, Lord of Tamba, 1750–1802)
1885-3-4	Dr William Lockhart (1811–1896)
1886-10-6	Rollin & Feuardent
1887-5-11	Messrs R. Whyte & Co
1888-8-3	Alfred I. Coe
1897-12-7	Rev H. Dixon
1902-6-8	Secretary of State for India (ex-August Friedrich Rudolf Hoernle, 1841–1918)
1908-6-5	Lady Raffles (d.1858) (= widow of Sir Stamford Raffles, 1781–1826)
1909-5-11	Mrs F. Bushell (= widow of Dr Stephen Wootton Bushell, 1844–1908)
1925-3-11	C.H. Dakers
1939-3-17	M. Comencini
1964-2-23	W.G. Walshe
1974-5-14	Spinks
1974-5-15	Spinks
1975-9-29	P.S.E. Cribb (= brother of Joe Cribb)
1975-11-22	J.E. Cribb (= Joe Cribb, British Museum)
1976-1-12	Anon
1976-9-16	Rev Ernest S. Box (1903–1994)
1978-9-19	Nicholas du Quesne Bird
1979-2-27	F. Burne (ex-John Wellington, Bishop of Shandong, 1889–1976)
1979-3-3	G. Goldthorp Hay
1979-3-4	Anon
1981-10-6	J. Bromwich
1981-12-16	J. Bromwich
1982-11-11	C. Eimer
1982-11-31	K. Courtenay (ex-Mayfield Hoard, Australia)
1983-5-26	R. Stedeford
1996-2-17	Rev Ernest S. Box (1903–1994) – the registration number indicates that this coin was acquired after the survey; its results are included in the tables

BMC	British Museum Catalogue
CH	Chinese Supplementary Register
E	Joseph Edkins (1823–1905)
GC	General Collection (19th century)
H	H.G. Heath (19th century)
K	Kingdom (19th century)
M	Miscellaneous (19th century)
W	Webster (19th century)

The only coin in this study that is not in the Department of Coins and Medals belongs to Mr. N.G. Rhodes (Treasurer of the Royal Numismatic Society).

Period
The periods or dynasties in which the coins were issued.

Obverse
The inscription on the front of the coin. The inscription is sometimes followed by two letters which indicate the script style:
CL = Clerk script (*Li shu*)
ST = Standard script (*Kai shu*)
CU = Cursive script (*Xing shu*)
GR = Grass script (*Cao shu*)
SE = Seal script (*Zhuan shu*)

All the coins used in this survey before AD 621 are written in a version of seal script; from then until 916 all are written in clerk script. From 916 until 1130 a range of scripts are used and indicated in the table; after 1130 all are written in standard script

Reverse
The inscription or marks on the back of the coin.

Mint, Denomination, Date, Weight
Where the coin was made, its value, its date of issue (all AD unless indicated otherwise), and its weight (in grammes).

Technique
The techniques used to analysis the coins:
XRFA = X-ray fluorescence (abraded) – the surface of the coin was cleaned prior to testing
XRFU = X-ray fluorescence (unabraded) – the surface of the coin was not cleaned prior to testing
AAS = Atomic absorption spectometry

For the AAS results, the copper content is not recorded.

Cu, Sn, Zn, Pb, Fe
Cu = Copper
Sn = Tin
Zn = Zinc
Pb = Lead
Fe = Iron

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
1	1883-8-2-86	Zhou	Yuan	-	-	1 jin	250 BC	9.8	XRFA	98	0.1	<0.1	0.7	0.9
2	1939-3-17-13	Zhou	Yuan	-	-	1 jin	250 BC	9.62	XRFA	97	<0.1	<0.1	0.1	3.1
3	1885-3-4-19	Zhou	Ming dao	-	-	1 huo	250 BC	2.42	XRFA	75	5.9	<0.1	18	0.6
4	1882-6-1-8	Zhou	Ming dao	-	-	1 huo	250 BC	2.34	XRFA	86	3.1	<0.1	11	0.2
5	1882-6-1-9	Zhou	Yi huo	-	-	1 huo	250 BC	1.25	XRFA	59	3.1	<0.1	38	0.5
6	1883-8-2-244	Zhou	Yi huo	-	-	1 huo	250 BC	1.55	XRFA	53	1.5	<0.1	44	0.6
7	1981-10-6-1	Qin	Banliang	-	-	1 cash	226 BC	5.95	XRFA	74	5.1	<0.1	17.5	0.1
8	Heath H1, BMC183	Qin	Banliang	-	-	1 cash	226 BC	8.12	XRFA	82	10.4	<0.1	6.4	0.1
9	1981-12-16-46	Qin	Banliang	-	-	1 cash	226 BC	9.2	XRFA	74	8	<0.1	15.9	0.4
10	1982-11-11-1	Qin	Banliang	-	-	1 cash	226 BC	9.1	XRFA	81	5.6	<0.1	12.4	0.1
11	1883-8-2-101	Han	Banliang	-	-	1 cash	200 BC	3.13	XRFA	63	12	<0.1	23	0.2
12	1883-8-2-96	Han	Banliang	-	-	1 cash	200 BC	4.71	XRFA	73	10	0.1	15	0.2
13	1882-6-1-13	Han	Banliang	-	-	1 cash	200 BC	6.29	XRFA	72	6	<0.1	20	0.3
14	1974-5-15-1	Han	Banliang	-	-	1 cash	200 BC	5.41	XRFA	77	15	<0.1	6.7	0.4
15	1870-5-7-14531	Han	Banliang	-	-	1 cash	175 BC	2.38	XRFA	62	7.9	0.1	26	0.3
16	Edkins E4, BMC216	Han	Banliang	-	-	1 cash	175 BC	2.89	XRFA	76	11	<0.1	11	0.1
17	1883-8-2-148	Han	Banliang	-	-	1 cash	175 BC	2.63	XRFA	72	9	<0.1	16	1.7
18	1883-8-2-182	Han	Banliang	-	-	1 cash	175 BC	2.41	XRFA	82	5.6	<0.1	12	0.1
19	BMC303	Han	Banliang [magnetic]	-	-	1 cash	150 BC	2.01	XRFA	96	<0.1	<0.1	0	3.9
20	1883-8-2-157	Han	Banliang [magnetic]	-	-	1 cash	150 BC	2.54	XRFA	92	4.8	<0.1	0.1	2.6
21	1883-8-2-118	Han	Banliang [magnetic]	-	-	1 cash	150 BC	2.19	XRFA	98	0.1	<0.1	0.2	1.8
22	1883-8-2-114	Han	Banliang [magnetic]	-	-	1 cash	150 BC	1.87	XRFA	95	1.6	0.9	0.9	1.8
23	1939-3-17-50	Wang Mang	Huoquan	-	-	1 cash	14	3.48	XRFA	87	6.9	<0.1	5.2	0.8
24	Chinese Sup. CH16	Wang Mang	Huoquan	-	-	1 cash	14	2.44	XRFA	85	4.8	<0.1	8.9	0.8
25	1870-5-7-14541	Wang Mang	Huoquan	-	-	1 cash	14	2.42	XRFA	74	5.3	0.2	19	0.7
26	General Coll. GC77	Wang Mang	Huoquan	-	-	1 cash	14	2.72	XRFA	77	9.8	0.2	12	0.6
27	1882-6-1-31	Wang Mang	Daquan wushi	-	-	50 cash	9	6.04	XRFA	87	5.2	<0.1	6.3	1.7
28	1882-6-1-29	Wang Mang	Daquan wushi	-	-	50 cash	9	5.6	XRFA	90	4	0.1	5.2	0.4
29	1939-3-17-38	Wang Mang	Daquan wushi	-	-	50 cash	9	4.27	XRFA	84	6.5	<0.1	7.8	1.6
30	1883-8-2-191	Wang Mang	Daquan wushi	-	-	50 cash	9	3.53	XRFA	91	3.4	<0.1	5	0.2
31	1883-8-2-190	Wang Mang	Daquan wushi	-	-	50 cash	9	2.42	XRFA	90	3.6	0.1	6.2	0.4
32	1939-3-17-42	Wang Mang	Daquan wushi	-	-	50 cash	9	2.76	XRFA	86	5.4	0.9	5.8	2.1
33	1939-3-17-47	Wang Mang	Xiaoquan zhiyi	-	-	1 cash	9	1.27	XRFA	79	10	0.2	8.3	1.8
34	1882-6-1-32	Wang Mang	Xiaoquan zhiyi	-	-	1 cash	9	0.75	XRFA	75	10	0.1	11	4
35	1981-12-16-81	Han	Wuzhu (dot below hole)	-	-	1 cash	70 BC	2.89	XRFA	89	5.1	0.9	2.9	2.2
36	1870-5-7-14533	Han	Wuzhu (dot below hole)	-	-	1 cash	70 BC	3.08	XRFA	88	4.2	0.4	3.4	4
37	Chinese Sup. CH38	Han	Wuzhu (line above hole)	-	-	1 cash	70 BC	2.99	XRFA	92	1.8	0.3	4.5	1.2
38	1981-12-16-84	Han	Wuzhu (line above hole)	-	-	1 cash	70 BC	3	XRFA	85	7.9	0.4	2.2	5
39	Chinese Sup. CH18	Han	Wuzhu (corners marked)	-	-	1 cash	70 BC	3.5	XRFA	77	3.5	0.3	19	0.6
40	1882-6-1-25	Han	Wuzhu	4 lines	-	1 cash	186	3.58	XRFA	73	7.7	0.2	19	0.2
41	1981-12-16-125	Han	Wuzhu	4 lines	-	1 cash	186	3.94	XRFA	73	6.8	0.4	20	0.2
42	BMC504	Han	Wuzhu	-	-	1 cash	150	3.37	XRFA	95	3.4	0.3	0.2	1.3
43	BMC507	Han	Wuzhu	-	-	1 cash	150	2.59	XRFA	92	6.4	0.3	0.4	1
44	BMC422	Han	Wuzhu	-	-	1 cash	70 BC	0.43	XRFA	47	5.4	<0.1	47	0.2
45	1909-5-11-14	Han	Wuzhu	-	-	1 cash	70 BC	0.7	XRFA	89	7.1	0.4	1	2.3
46	1983-5-26-9	Shu	Zhibai wuzhu	-	-	100 cash	214	3.21	XRFA	82	4.1	0.3	13	0.2
47	1981-12-16-135	Shu	Zhibai wuzhu	-	-	100 cash	214	5.22	XRFA	78	3.5	0.3	18	0.2

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
48	BMC426	Shu	Sizhu	-	-	1 cash	454	2.29	XRFA	75	2.9	0.2	22	0.3
49	1883-8-2-3657	Shu	Sizhu	xiao jian	-	1 cash	454	1.84	XRFU	78	3.7	<0.1	18	0.3
50	1883-8-2-3658	Shu	Sizhu	xiao jian	-	1 cash	454	1.04	XRFU	76	7.8	0.1	15	0.9
51	1883-8-2-3651	Shu	Sizhu	xiao jian	-	1 cash	454	0.67	XRFU	74	4	0.6	20	0.6
52	General Coll. GC73	Northern Wei	Yong'an wuzhu	-	-	1 cash	510	3.55	XRFA	73	9.5	<0.1	17	0.6
53	Chinese Sup. CH21	Northern Wei	Yong'an wuzhu	-	-	1 cash	510	3.03	XRFA	67	14	0.2	18	0.6
54	1882-6-1-61	Wei	Wuzhu	-	-	1 cash	540	2.15	XRFA	75	10	<0.1	14	0.6
55	1883-8-2-232	Wei	Wuzhu	-	-	1 cash	540	3.01	XRFA	73	4.9	<0.1	22	0.3
56	General Coll. GC75	Northern Qi	Changping wuzhu	-	-	1 cash	553	3.88	XRFA	74	12	<0.1	13	0.2
57	1883-8-2-3647	Northern Qi	Changping wuzhu	-	-	1 cash	553	3.53	XRFA	73	12	2.9	12	0.4
58	1981-12-16-137	Northern Zhou	Wuxing dabu	-	-	1 cash	574	4.34	XRFA	74	6.1	0.3	19	0.6
59	1981-12-16-138	Northern Zhou	Wuxing dabu	-	-	1 cash	574	4.49	XRFA	78	4.7	0.3	15	2.5
60	1847-11-9-28	Chen	Taihuo liuzhu	-	-	1 cash	579	3.17	XRFA	70	13	0.3	15	2.1
61	1885-3-4-23	Chen	Taihuo liuzhu	-	-	1 cash	579	2.65	XRFA	74	7.4	<0.1	19	0.3
62	General Coll. GC84	Tang	Kaiyuan tongbao	-	-	1 cash	621	4	XRFA	69	15	<0.1	16	0.4
63	General Coll. GC86	Tang	Kaiyuan tongbao	-	-	1 cash	621	3.79	XRFA	79	17	<0.1	3.9	0.2
64	1884-5-11-721	Tang	Kaiyuan tongbao	crescent	-	1 cash	621	3.38	XRFA	94	1	<0.1	2.6	2.2
65	1883-8-2-274	Tang	Kaiyuan tongbao	crescent	-	1 cash	621	3.7	XRFA	85	11	0.2	1.4	2.5
66	1884-5-11-702	Tang	Kaiyuan tongbao	crescent	-	1 cash	621	3.06	XRFA	75	11	<0.1	13	0.7
67	1884-5-11-768	Tang	Kaiyuan tongbao	crescent	-	1 cash	621	2.95	XRFA	70	17	<0.1	10	2.8
68	1884-5-11-730	Tang	Kaiyuan tongbao	crescent	-	1 cash	621	3.29	XRFA	68	8.2	<0.1	23	0.3
69	1884-5-11-787	Tang	Kaiyuan tongbao	crescent	-	1 cash	621	4.23	XRFA	78	10	<0.1	9	2.4
70	1883-8-2-283	Tang	Kaiyuan tongbao	2 crescents	-	1 cash	621	3.44	XRFA	69	0.2	<0.1	29	1.9
71	1884-5-11-778	Tang	Kaiyuan tongbao	2 crescents	-	1 cash	621	2.86	XRFA	79	15	<0.1	5.5	0.2
72	1884-5-11-699	Tang	Kaiyuan tongbao	dot	-	1 cash	621	3.26	XRFA	67	12	<0.1	20	0.3
73	1884-5-11-700	Tang	Kaiyuan tongbao	dot	-	1 cash	621	2.99	XRFA	73	10	<0.1	16	0.2
74	1884-5-11-660	Tang	Kaiyuan tongbao [dot]	-	-	1 cash	621	2.68	XRFA	69	5.9	<0.1	23	2.6
75	1884-5-11-661	Tang	Kaiyuan tongbao	-	-	1 cash	621	3.58	XRFA	68	5.8	<0.1	21	5
76	1884-5-11-838	Tang	Qianfeng quanbao	-	-	10 cash	666	3.52	XRFA	81.3	14	<0.3	4.1	0.2
77	1884-5-11-839	Tang	Qianfeng quanbao	-	-	10 cash	666	3.65	XRFU	72	16.7	<0.1	11.2	0.1
78	1886-10-6-775	Tang	Qianyuan zhongbao	circle	-	10 cash	759	12.12	XRFU	36.1	17.7	<0.1	44.5	1.7
79	1884-5-11-879	Tang	Qianyuan zhongbao	circle	-	10 cash	759	11.12	XRFU	52	16.7	<0.1	31.1	0.4
80	1996-2-17-264	Tang	Qianyuan zhongbao	circle	-	10 cash	759	15.02	XRFA	80	9.9	<0.1	7.9	0.1
81	Edkins E25	Tang	Qianyuan zhongbao	circle	[modern copy]	10 cash	759	16.96	XRFU	71	5.4	15.2	7.2	0.9
82	1884-5-11-883	Tang	Qianyuan zhongbao	-	-	10 cash	759	6.44	XRFU	65	16	0.5	18.7	0.2
83	1884-5-11-842	Tang	Qianyuan zhongbao	-	-	10 cash	759	5.57	XRFA	68	16	0.4	15	0.9
84	1902-6-8-198	Tang	Qianyuan zhongbao	-	[from Xinjiang]	10 cash	759	5.15	XRFU	6.8	18	<0.1	74	1
85	1902-6-8-197	Tang	Qianyuan zhongbao	-	[from Xinjiang]	10 cash	759	6	XRFA	68	18.1	<0.3	11.6	0.75
86	1884-5-11-844	Tang	Qianyuan zhongbao	-	-	10 cash	759	4.51	XRFA	75.2	9.6	<0.3	13.8	0.3
87	1884-5-11-882	Tang	Qianyuan zhongbao	-	-	10 cash	759	3.2	XRFU	79	13	0.3	7.9	0.2
88	1883-8-2-309	Tang	Qianyuan zhongbao	dot	-	1 cash	759	3.71	XRFU	75	12	0.5	11.6	1.1
89	1884-5-11-859	Tang	Qianyuan zhongbao	crescent	-	1 cash	759	2.96	XRFA	76	12	0.4	11	0.6
90	1884-5-11-880	Tang	Qianyuan zhongbao	crescent	-	1 cash	759	3.35	XRFA	76	13	0.5	11	0.7
91	1908-6-5-145	Tang	Qianyuan zhongbao	-	-	1 cash	759	2.93	XRFA	59	19	0.4	19	2.6
92	1884-5-11-846	Tang	Qianyuan zhongbao	-	-	1 cash	759	2.82	XRFA	64	20	0.5	13	2.1
93	1884-5-11-881	Tang	Qianyuan zhongbao	-	-	1 cash	759	2.8	XRFA	77	9.9	<0.1	9.3	0.9
94	1902-6-8-160	Tang	Qianyuan zhongbao	-	[from Xinjiang]	1 cash	759	2.6	XRFA	25	14	<0.1	60	1.1
95	1902-6-8-159	Tang	Qianyuan zhongbao	-	[from Xinjiang]	1 cash	759	2.48	XRFA	44	13	0.2	43	0.7

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
96	1902-6-8-166	Tang	Dali yuanbao	-	[from Xinjiang]	10 cash	769	3.27	XRFA	37	15	<0.1	46	1.3
97	1902-6-8-167	Tang	Dali yuanbao	-	[from Xinjiang]	10 cash	769	3.34	XRFA	49	13	<0.1	38	0.7
98	1884-5-11-930	Tang	Kaiyuan tongbao	hong	Hongzhou	1 cash	845	3.09	XRFA	71	12	<0.1	17	0.2
99	1883-8-2-328	Tang	Kaiyuan tongbao	hong	Hongzhou	1 cash	845	3.19	XRFA	72	12	0.2	15	0.2
100	1883-8-2-325	Tang	Kaiyuan tongbao	xuan	Xuanzhou	1 cash	845	3.86	XRFA	73	15	<0.1	12	0.7
101	1882-6-1-92	Tang	Kaiyuan tongbao	xuan	Xuanzhou	1 cash	845	4.1	XRFA	75	14	0.2	10	0.5
102	1884-5-11-895	Tang	Kaiyuan tongbao	xi	Xizhou	1 cash	845	3.78	XRFA	80	11	0.2	8.6	0.2
103	1883-8-2-358	Tang	Kaiyuan tongbao	xi	Xizhou	1 cash	845	3.49	XRFA	83	8.8	0.3	7.7	0.2
104	1883-8-2-351	Tang	Kaiyuan tongbao	bao	Unidentified	1 cash	845	2.31	XRFA	80	2.9	0.2	16	1.3
105	Heath H14	Tang	Kaiyuan tongbao	yang	Yangzhou	1 cash	845	3.62	XRFA	72	16	0.2	9.7	2.4
106	1884-5-11-910	Tang	Kaiyuan tongbao	yang	Yangzhou	1 cash	845	3.68	XRFA	72	15	0.3	12	0.7
107	1884-5-11-892	Tang	Kaiyuan tongbao	jing /cres.	Chang'an	1 cash	845	4.08	XRFA	77	14	0.2	8	0.2
108	1884-5-11-890	Tang	Kaiyuan tongbao	jing /cres.	Chang'an	1 cash	845	3.72	XRFA	74	13	0.2	12	0.3
109	1882-6-1-90	Tang	Kaiyuan tongbao	luo	Luoyang	1 cash	845	3.15	XRFA	76	16	0.2	6.9	0.7
110	1883-8-2-314	Tang	Kaiyuan tongbao	luo	Luoyang	1 cash	845	3.45	XRFA	77	14	0.3	8.4	0.3
111	Webster W5	Tang	Kaiyuan tongbao	lan	Lantian	1 cash	845	3.35	XRFA	74	18	0.3	6.3	1.1
112	1884-5-11-900	Tang	Kaiyuan tongbao	lan	Lantian	1 cash	845	2.54	XRFA	78	12	0.2	10	0.2
113	1884-5-11-906	Tang	Kaiyuan tongbao	fu	Fuzhou	1 cash	845	3.11	XRFA	67	19	0.2	12	2.1
114	1884-5-11-905	Tang	Kaiyuan tongbao	fu	Fuzhou	1 cash	845	3.91	XRFA	79	14	0.2	6.7	0.2
115	1884-5-11-908	Tang	Kaiyuan tongbao	xiang /cres.	Xiangzhou	1 cash	845	3.32	XRFA	78	11	0.2	11	0.2
116	1883-8-2-359	Tang	Kaiyuan tongbao	xiang	Xiangzhou	1 cash	845	3.96	XRFA	73	11	0.6	15	0.4
117	1884-5-11-909	Tang	Kaiyuan tongbao	xiang /cres.	Xiangzhou	1 cash	845	3.08	XRFA	75	13	0.5	12	0.2
118	1884-5-11-910	Tang	Kaiyuan tongbao	xiang	Xiangzhou	1 cash	845	3.23	XRFA	82	9.6	0.5	7.6	0.2
119	1882-6-1-87	Tang	Kaiyuan tongbao	run	Runzhou	1 cash	845	4.99	XRFA	72	16	0.4	11	0.6
120	1883-8-2-333	Tang	Kaiyuan tongbao	run	Runzhou	1 cash	845	3.71	XRFA	75	14	0.5	10	0.3
121	1884-5-11-646	Tang	Kaiyuan tongbao	yong	Yongzhou	1 cash	845	2.62	XRFA	73	18	0.5	7.4	1.5
122	1884-5-11-917	Tang	Kaiyuan tongbao	tan	Tanzhou	1 cash	845	3.42	XRFA	79	11	0.5	9.1	0.3
123	1884-5-11-918	Tang	Kaiyuan tongbao	tan	Tanzhou	1 cash	845	3.72	XRFA	70	13	0.4	16	0.2
124	1884-5-11-919	Tang	Kaiyuan tongbao	ping	Pingzhou	1 cash	845	3.58	XRFA	74	18	0.5	7.8	0.2
125	1884-5-11-920	Tang	Kaiyuan tongbao	ping	Pingzhou	1 cash	845	3.34	XRFA	61	23	0.4	14	0.8
126	1884-5-11-921	Tang	Kaiyuan tongbao	e	Ezhou	1 cash	845	3.34	XRFA	52	29	0.3	19	0.2
127	Edkins E28	Tang	Kaiyuan tongbao	e	Ezhou	1 cash	845	3.62	XRFA	69	17	0.8	13	0.2
128	Webster W3	Tang	Kaiyuan tongbao	liang	Liangzhou	1 cash	845	3.14	XRFA	74	14	0.4	11	0.3
129	1883-8-2-339	Tang	Kaiyuan tongbao	liang	Liangzhou	1 cash	845	2.44	XRFA	75	12	0.5	13	0.2
130	1884-5-11-639	Tang	Kaiyuan tongbao	guang	Guangzhou	1 cash	845	3	result unreliable					
131	Webster W6	Tang	Kaiyuan tongbao	guang	Guangzhou	1 cash	845	3.93	XRFA	77	12	0.5	9.8	0.2
132	Webster W4	Tang	Kaiyuan tongbao	zi	Zizhou	1 cash	845	3.72	XRFA	75	15	0.4	9.8	0.2
133	1884-5-11-648	Tang	Kaiyuan tongbao	zi	Zizhou	1 cash	845	2.73	XRFA	77	14	0.5	7.8	0.3
134	1884-5-11-643	Tang	Kaiyuan tongbao	jing	Jingzhou	1 cash	845	3.57	XRFA	78	9.9	0.4	12	0.2
135	1884-5-11-644	Tang	Kaiyuan tongbao	jing	Jingzhou	1 cash	845	2.98	XRFA	75	13	0.5	11	0.2
136	Edkins E31	Tang	Kaiyuan tongbao	xing	Xingzhou	1 cash	845	2.83	XRFA	75	11	0.4	14	0.2
137	1882-6-1-95	Tang	Kaiyuan tongbao	xing	Xingzhou	1 cash	845	4.1	XRFA	78	12	0.5	9.9	0.2
138	1883-8-2-322	Tang	Kaiyuan tongbao	yue	Yuezhou	1 cash	845	4.09	XRFA	72	19	0.5	8.3	0.3
139	Webster W8	Tang	Kaiyuan tongbao	yue	Yuezhou	1 cash	845	3.88	XRFA	74	14	0.4	11	0.2
140	1884-5-11-652	Tang	Kaiyuan tongbao	gui	Guizhou	1 cash	845	2.84	XRFA	70	15	0.3	13	0.4
141	1883-8-2-347	Tang	Kaiyuan tongbao	gui	Guizhou	1 cash	845	3.54	XRFA	72	15	0.5	12	0.2
142	Webster W7	Tang	Kaiyuan tongbao	chang	Changzhou	1 cash	845	3.58	XRFA	73	14	0.6	12	0.7
143	1884-5-11-885	Tang	Kaiyuan tongbao	chang	Changzhou	1 cash	845	3.76	XRFA	70	15	0.4	14	0.4

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
144	1883-8-2-425	Tang rebel	Shuntian yuanbao	crescent	-	10 cash	759	17.3	XRFA	78	13	0.4	8.5	0.2
145	1882-6-1-100	Tang rebel	Shuntian yuanbao	crescent	-	10 cash	759	19.46	XRFA	72	12	0.4	15	0.8
146	1884-5-11-956	Later Han	Hanyuan tongbao CL	crescent	-	1 cash	948	3.24	XRFA	77	11	0.9	11	0.3
147	1883-8-2-408	Later Han	Hanyuan tongbao CL	crescent	-	1 cash	948	3.45	XRFA	72	8.9	0.6	18	0.2
148	1883-8-2-392	Posterior Zhou	Zhouyuan tongbao CL	line	-	1 cash	955	3.03	XRFA	68	11	0.9	19	1.5
149	1870-5-7-14556	Posterior Zhou	Zhouyuan tongbao CL	line	-	1 cash	955	4.18	XRFA	75	9.1	0.9	14	0.6
150	1883-8-2-396	Posterior Zhou	Zhouyuan tongbao CL	dot	-	1 cash	955	3.74	XRFA	73	8.2	1	17	0.7
151	1884-5-11-988	Posterior Zhou	Zhouyuan tongbao CL	dot	-	1 cash	955	3.53	XRFA	75	12	0.9	12	0.2
152	1884-5-11-963	Former Shu	Tongzheng yuanbao CL	crescent	-	1 cash	916	2.54	XRFA	76	3.7	0.4	19	0.2
153	1884-5-11-967	Former Shu	Tongzheng yuanbao CL	crescent	-	1 cash	916	3.79	XRFA	76	4.5	0.3	19	0.2
154	1884-5-11-1009	Former Shu	Tianhan yuanbao CL	-	-	1 cash	917	3.87	XRFA	71	2.3	0.3	26	0.1
155	1882-6-1-112	Former Shu	Tianhan yuanbao CL	-	-	1 cash	917	3.05	XRFA	82	0.9	0.3	17	0.1
156	1884-5-11-977	Former Shu	Guangtian yuanbao CL	crescent	-	1 cash	918	2.42	XRFA	83	2.5	0.4	14	0.1
157	1884-5-11-979	Former Shu	Guangtian yuanbao CL	crescent	-	1 cash	918	2.92	XRFA	80	1.4	0.5	18	0.2
158	Kingdom K16	Former Shu	Qiande yuanbao CL	-	-	1 cash	919	2.93	XRFA	79	5.6	0.5	14	0.1
159	1884-5-11-974	Former Shu	Qiande yuanbao CL	-	-	1 cash	919	3.11	XRFA	82	2.2	0.5	16	0.1
160	1884-5-11-971	Former Shu	Xiankang yuanbao CL	-	-	1 cash	925	2.28	XRFA	75	2	0.4	22	0.2
161	1884-5-11-972	Former Shu	Xiankang yuanbao CL	-	-	1 cash	925	3.67	XRFA	83	2.6	0.4	14	0.1
162	1884-5-11-984	Later Shu	Guangzheng tongbao CL	-	-	1 cash	938	2.97	XRFA	78	11	0.6	10	0.8
163	1884-5-11-985	Later Shu	Guangzheng tongbao CL	-	-	1 cash	938	3.21	XRFA	77	5.5	0.4	17	0.2
164	General Coll. GC96	Southern Tang	Kaiyuan tongbao SE	-	-	1 cash	966	3.52	XRFA	72	13	0.4	15	0.1
165	1883-8-2-252	Southern Tang	Kaiyuan tongbao SE	-	-	1 cash	966	3.17	XRFA	66	14	0.2	20	0.1
166	1883-8-2-410	Southern Tang	Tangguo tongbao SE	-	-	1 cash	955	3.6	XRFA	69	12	0.7	18	0.2
167	1883-8-2-412	Southern Tang	Tangguo tongbao SE	-	-	1 cash	955	3.6	XRFA	71	10	0.4	18	0.4
168	1884-5-11-945	Southern Tang	Tangguo tongbao SE	-	-	1 cash	955	2.97	XRFA	71	12	0.4	16	0.2
169	1884-5-11-946	Southern Tang	Tangguo tongbao SE	dot	-	1 cash	955	3.18	XRFA	72	11	0.4	16	0.3
170	1884-5-11-947	Southern Tang	Tangguo tongbao ST	dot	-	1 cash	955	2.86	XRFA	73	9.5	0.4	17	0.3
171	1883-8-2-413	Southern Tang	Tangguo tongbao CL	-	-	1 cash	955	1.79	XRFA	74	14	0.5	11	0.3
172	Heath H21	Southern Tang	Tangguo tongbao CL	-	-	1 cash	955	1.81	XRFA	69	10	0.5	20	0.5
173	1882-6-1-119	Southern Tang	Tangguo tongbao ST	-	-	1 cash	955	2.65	XRFA	71	10	0.4	19	0.2
174	1883-8-2-415	Southern Tang	Tangguo tongbao ST	-	-	1 cash	955	3.59	XRFA	68	13	0.3	19	0.2
175	Webster W12	Southern Tang	Datang tongbao CL	-	-	1 cash	944	2.35	XRFA	70	18	<0.1	11	0.3
176	1883-8-2-417	Southern Tang	Datang tongbao CL	-	-	1 cash	944	2.62	XRFA	69	15	0.7	14	0.5
177	1884-5-11-939	Southern Han	Qianheng zhongbao CL	-	-	1 cash	917	2.24	XRFA	74	14	0.5	11	0.4
178	1884-5-11-960	Southern Han	Qianheng zhongbao CL	-	-	1 cash	917	2.83	XRFA	77	13	0.6	9.5	0.2
179	1888-8-3-1	Southern Han	Qianheng zhongbao CL	-	Guangxi Provincial	1 cash	917	3.34	XRFA	-	-	-	100	-
180	1888-8-3-4	Southern Han	Qianheng zhongbao CL	-	Guangxi Provincial	1 cash	917	3.71	XRFA	-	-	-	100	-
181	1888-8-3-5	Southern Han	Qianheng zhongbao CL	-	Guangxi Provincial	1 cash	917	4.01	XRFA	-	-	-	100	-
182	1925-3-11-147	Southern Han	Qianheng zhongbao CL	-	Guangxi Provincial	1 cash	917	4.91	XRFA	-	-	-	100	-
183	1888-8-3-2	Southern Han	Qianheng zhongbao CL	yong	Guangxi Provincial	1 cash	917	4.49	XRFA	-	-	-	100	-
184	1883-8-2-421	Southern Han	Qianheng zhongbao CL	yong	Guangxi Provincial	1 cash	917	3.9	XRFA	-	-	-	100	-
185	1888-8-3-3	Southern Han	Qianheng zhongbao CL	yong	Guangxi Provincial	1 cash	917	4.2	XRFA	-	-	-	100	-
186	1883-8-2-433	Song	Songyuan tongbao CL	line	-	1 cash	968	3.17	XRFA	75	9.4	1.1	13	0.5
187	1883-8-2-434	Song	Songyuan tongbao CL	line	-	1 cash	968	3.86	XRFA	68	7.1	0.9	23	1.2
188	1883-8-2-443	Song	Songyuan tongbao CL	dot	-	1 cash	968	3.93	XRFA	65	12	0.9	22	0.2
189	1883-8-2-442	Song	Songyuan tongbao CL	dot	-	1 cash	968	3.15	XRFA	73	9.7	1	15	1.4
190	1882-6-1-124	Song	Taiping tongbao CL	-	-	1 cash	977	3.06	XRFA	67	12	1	20	0.2
191	1870-5-7-14557	Song	Taiping tongbao CL	-	-	1 cash	977	3.42	XRFA	77	15	1	6.6	0.7

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
192	Edkins E39	Song	Chunhua yuanbao CL	-	-	1 cash	990	3.52	XRFA	69	14	1.4	16	0.2
193	1882-6-1-125	Song	Chunhua yuanbao CL	-	-	1 cash	990	3.45	XRFA	70	10	1.1	19	0.2
194	1883-8-2-463	Song	Chunhua yuanbao CU	-	-	1 cash	990	3.43	XRFA	69	12	0.3	18	0.2
195	1883-8-2-462	Song	Chunhua yuanbao CU	-	-	1 cash	990	4.14	XRFA	64	13	0.3	22	0.2
196	General Coll. GC311	Song	Chunhua yuanbao GR	-	-	1 cash	990	3.71	XRFA	70	13	0.3	18	0.1
197	1883-8-2-465	Song	Chunhua yuanbao GR	-	-	1 cash	990	3.37	XRFA	70	12	0.3	18	0.2
198	1883-8-2-466	Song	Zhidao tongbao CL	-	-	1 cash	995	3.72	XRFA	68	15	0.3	17	0.2
199	Heath H25	Song	Zhidao tongbao CL	-	-	1 cash	995	3.9	XRFA	71	14	0.3	15	0.1
200	General Coll. GC109	Song	Zhidao tongbao CU	-	-	1 cash	995	3.95	XRFA	66	15	0.3	18	0.3
201	1883-8-2-468	Song	Zhidao tongbao CU	-	-	1 cash	995	3.39	XRFA	76	6.7	0.3	17	0.2
202	1870-5-7-14563	Song	Zhidao tongbao GR	-	-	1 cash	995	4.37	XRFA	64	14	0.3	21	0.2
203	1883-8-2-471	Song	Zhidao tongbao GR	-	-	1 cash	995	3.08	XRFA	69	13	0.3	18	0.1
204	1870-5-7-14566	Song	Xianping yuanbao CL	-	-	1 cash	999	4.18	XRFA	71	13	0.3	15	0.2
205	1882-6-1-130	Song	Xianping yuanbao CL	-	-	1 cash	999	3.8	XRFA	71	12	0.3	17	0.2
206	1870-5-7-14567	Song	Jingde yuanbao ST	-	-	1 cash	1005	4.23	XRFA	71	9.8	0.3	18	0.1
207	1883-8-2-476	Song	Jingde yuanbao ST	-	-	1 cash	1005	3.6	XRFA	72	10	0.5	17	0.2
208	1883-8-2-478	Song	Xiangfu tongbao ST	-	-	1 cash	1009	3.3	XRFA	68	11	0.5	21	0.4
209	1882-6-1-132	Song	Xiangfu tongbao ST	-	-	1 cash	1009	4	XRFA	73	9.4	0.3	17	0.3
210	Kingdom K28	Song	Xiangfu tongbao ST	-	-	1 cash	1009	3.74	XRFA	66	12	0.2	22	0.1
211	Miscellaneous M30	Song	Xiangfu tongbao ST	-	-	1 cash	1009	2.66	XRFA	71	9.3	0.2	19	0.3
212	1883-8-2-482	Song	Xiangfu yuanbao ST	-	-	1 cash	1009	3.52	XRFA	78	9.2	0.2	13	0.1
213	1870-5-7-14572	Song	Xiangfu yuanbao ST	-	-	1 cash	1009	3.75	XRFA	71	12	0.4	16	0.3
214	General Coll. GC123	Song	Xiangfu yuanbao ST	-	[Vietnamese copy?]	1 cash	1009	2.98	XRFA	75	3.7	0.4	20	0.1
215	1883-8-2-484	Song	Xiangfu yuanbao ST	-	[Vietnamese copy?]	1 cash	1009	2.79	XRFA	77	4.7	0.4	18	0.2
216	1883-8-2-490	Song	Tianxi tongbao ST	-	-	1 cash	1018	3.77	XRFA	75	12	0.2	13	0.2
217	1882-6-1-137	Song	Tianxi tongbao ST	-	-	1 cash	1018	4.21	XRFA	65	11	0.2	24	0.2
218	Miscellaneous M36	Song	Tianxi tongbao ST	-	-	1 cash	1018	2.78	XRFA	73	8.9	0.2	17	0.2
219	Kingdom K31	Song	Tianxi tongbao ST	-	-	1 cash	1018	3.35	XRFA	69	13	0.2	18	0.2
220	1886-10-6-837	Song	Tianxi tongbao SE	-	-	1 cash	1018	3.11	XRFA	61	4.6	<0.1	34	0.2
221	Heath H29	Song	Tiansheng yuanbao ST	-	-	1 cash	1023	3.88	XRFA	67	8.1	0.2	24	0.2
222	1870-5-7-14580	Song	Tiansheng yuanbao ST	-	-	1 cash	1023	4	XRFA	72	8.6	0.2	19	0.2
223	Heath H30	Song	Tiansheng yuanbao SE	-	-	1 cash	1023	4.15	XRFA	69	10	0.2	21	0.2
224	General Coll. GC138	Song	Tiansheng yuanbao SE	-	-	1 cash	1023	3.7	XRFA	72	12	0.2	16	0.2
225	1883-8-2-498	Song	Mingdao yuanbao ST	-	-	1 cash	1032	3.75	XRFA	71	8.4	0.4	20	0.4
226	1882-6-1-145	Song	Mingdao yuanbao ST	-	-	1 cash	1032	2.59	XRFA	69	10	0.3	21	0.2
227	1883-8-2-497	Song	Mingdao yuanbao SE	-	-	1 cash	1032	4.06	XRFA	67	12	0.3	21	0.1
228	Heath H31	Song	Mingdao yuanbao SE	-	-	1 cash	1032	3.77	XRFA	72	10	0.2	18	0.2
229	1870-5-7-14604	Song	Jingyou yuanbao ST	-	-	1 cash	1034	3.69	XRFA	68	12	0.2	20	0.2
230	Miscellaneous M54	Song	Jingyou yuanbao ST	-	-	1 cash	1034	3.94	XRFA	75	11	0.2	14	0.2
231	Edkins E56	Song	Jingyou yuanbao SE	-	-	1 cash	1034	2.82	XRFA	73	11	0.2	16	0.2
232	Heath H35	Song	Jingyou yuanbao SE	-	-	1 cash	1034	3.47	XRFA	70	9.1	<0.1	21	0.1
233	General Coll. GC162	Song	Huangsong tongbao CL	-	-	1 cash	1039	3.42	XRFA	69	14	0.6	16	0.2
234	General Coll. GC164	Song	Huangsong tongbao CL	-	-	1 cash	1039	4	XRFA	71	9.3	<0.1	19	0.2
235	Miscellaneous M240	Song	Huangsong tongbao CL	-	-	1 cash	1039	3.61	XRFA	71	13	<0.1	12	3.4
236	1883-8-2-515	Song	Huangsong tongbao CL	-	-	1 cash	1039	4.15	XRFA	72	12	0.2	15	0.2
237	General Coll. GC165	Song	Huangsong tongbao CL	-	-	1 cash	1039	2.93	XRFA	70	7.5	<0.1	22	0.2
238	General Coll. GC166	Song	Huangsong tongbao CL	-	-	1 cash	1039	3.43	XRFA	72	11	0.1	17	0.1
239	1883-8-2-513	Song	Huangsong tongbao ST	-	-	1 cash	1039	3.29	XRFA	72	12	<0.1	16	0.1

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
240	1870-5-7-14591	Song	Huangsong tongbao ST	-	-	1 cash	1039	4.29	XRFA	70	11	0.1	19	0.2
241	1870-5-7-14592	Song	Huangsong tongbao ST	-	-	1 cash	1039	3.46	XRFA	71	9.2	<0.1	19	0.2
242	1883-8-2-514	Song	Huangsong tongbao ST	-	-	1 cash	1039	4.09	XRFA	70	12	<0.1	18	0.3
243	1886-10-6-816	Song	Huangsong tongbao SE	-	-	1 cash	1039	3.29	XRFA	70	14	<0.1	16	0.1
244	1883-8-2-508	Song	Huangsong tongbao SE	-	-	1 cash	1039	3.27	XRFA	71	12	0.1	16	0.2
245	1882-6-1-153	Song	Huangsong tongbao SE	-	[Vietnamese copy]	1 cash	1039	3.23	XRFA	62	9.9	<0.1	28	0.2
246	1883-8-2-510	Song	Huangsong tongbao SE	-	[Vietnamese copy]	1 cash	1039	3.69	XRFA	66	11	<0.1	23	0.2
247	1882-6-1-154	Song	Qingli zhongbao ST	-	-	2 cash	1045	6.77	XRFA	77	6.9	<0.1	16	0.1
248	1882-6-1-156	Song	Qingli zhongbao ST	-	-	2 cash	1045	6	XRFA	75	5.2	<0.1	19	0.2
249	1883-8-2-522	Song	Qingli zhongbao ST	-	-	2 cash	1045	7.53	XRFA	76	9.5	<0.1	14	0.1
250	Edkins E60	Song	Qingli zhongbao ST	-	-	2 cash	1045	6.25	XRFA	67	10	<0.1	23	0.2
251	General Coll. GC171	Song	Zhihe tongbao ST	-	-	1 cash	1054	3.41	XRFA	75	7.2	<0.1	18	0.1
252	Edkins E63	Song	Zhihe tongbao ST	-	-	1 cash	1054	3.59	XRFA	70	6.4	<0.1	23	0.2
253	1882-6-1-157	Song	Zhihe yuanbao ST	-	-	1 cash	1054	3.13	XRFA	72	10	<0.1	18	0.2
254	Miscellaneous M55	Song	Zhihe yuanbao ST	-	-	1 cash	1054	3.4	XRFA	71	13	<0.1	16	0.5
255	1884-5-11-2065	Song	Zhihe yuanbao ST	-	-	1 cash	1054	3.36	XRFA	65	15	<0.1	19	0.1
256	General Coll. GC167	Song	Zhihe yuanbao ST	-	-	1 cash	1054	4.09	XRFA	70	17	<0.1	13	0.1
257	General Coll. GC169	Song	Zhihe yuanbao SE	-	-	1 cash	1054	2.76	XRFA	69	5.7	<0.1	25	0.2
258	Edkins E61	Song	Zhihe yuanbao SE	-	-	1 cash	1054	4.27	XRFA	72	6.3	<0.1	21	0.2
259	Edkins E62	Song	Zhihe yuanbao SE	-	-	1 cash	1054	4.21	XRFA	75	7.4	<0.1	17	0.1
260	1882-6-1-158	Song	Zhihe yuanbao SE	-	-	1 cash	1054	2.65	XRFA	71	6.1	<0.1	23	0.1
261	1908-6-5-123	Song	Zhihe tongbao SE	-	-	1 cash	1054	3.82	XRFA	72	7.8	<0.1	20	0.2
262	1883-8-2-526	Song	Zhihe tongbao SE	-	-	1 cash	1054	3.38	XRFA	72	7.6	<0.1	20	0.3
263	1883-8-2-540	Song	Jiayou tongbao CL	-	-	1 cash	1057	3.24	XRFA	76	8.3	<0.1	15	0.1
264	1883-8-2-538	Song	Jiayou tongbao CL	-	-	1 cash	1057	2.89	XRFA	75	7.1	<0.1	17	0.2
265	1870-5-7-14606	Song	Jiayou tongbao ST	-	-	1 cash	1057	4.11	XRFA	76	5.7	<0.1	18	0.2
266	Edkins E67	Song	Jiayou tongbao ST	-	-	1 cash	1057	4.05	XRFA	70	13	<0.1	17	0.2
267	General Coll. GC175	Song	Jiayou tongbao SE	-	-	1 cash	1057	3.58	XRFA	73	10	<0.1	16	0.3
268	1870-5-7-14607	Song	Jiayou tongbao SE	-	-	1 cash	1057	4.13	XRFA	70	7.1	<0.1	23	0.1
269	1882-6-1-161	Song	Jiayou yuanbao CL	-	-	1 cash	1057	3.42	XRFA	78	10	<0.1	11	0.5
270	1908-6-5-77	Song	Jiayou yuanbao CL	-	-	1 cash	1057	3.68	XRFA	69	13	<0.1	18	0.3
271	1883-8-2-537	Song	Jiayou yuanbao ST	-	-	1 cash	1057	4.46	XRFA	70	7.2	0.4	22	0.2
272	Edkins E65	Song	Jiayou yuanbao ST	-	-	1 cash	1057	4.36	XRFA	66	11	<0.1	23	0.3
273	General Coll. GC184	Song	Jiayou yuanbao SE	-	-	1 cash	1057	3.46	XRFA	65	11	<0.1	24	0.2
274	1883-8-2-534	Song	Jiayou yuanbao SE	-	-	1 cash	1057	2.74	XRFA	76	12	0.2	11	0.2
275	General Coll. GC192	Song	Zhiping tongbao ST	-	-	1 cash	1064	3.34	XRFA	75	6.9	<0.1	18	0.1
276	General Coll. GC191	Song	Zhiping tongbao ST	-	-	1 cash	1064	2.72	XRFA	76	6.4	<0.1	17	0.1
277	1883-8-2-548	Song	Zhiping tongbao SE	-	-	1 cash	1064	2.93	XRFA	73	5.1	0.2	21	0.2
278	1883-8-2-547	Song	Zhiping tongbao SE	-	-	1 cash	1064	2.76	XRFA	76	6.9	0.2	17	0.3
279	1870-5-7-14609	Song	Zhiping yuanbao ST	-	-	1 cash	1064	4.16	XRFA	67	9.2	<0.1	23	0.2
280	1883-8-2-559	Song	Zhiping yuanbao ST	-	-	1 cash	1064	3.1	XRFA	69	9	<0.1	22	0.1
281	1883-8-2-542	Song	Zhiping yuanbao SE	-	-	1 cash	1064	4.04	XRFA	69	8.4	0.2	23	0.2
282	1870-5-7-14611	Song	Zhiping yuanbao SE	-	-	1 cash	1064	3.59	XRFA	68	11	<0.1	20	0.2
283	1883-8-2-585	Song	Xining yuanbao CL	-	-	1 cash	1068	3.87	XRFU	73	8.2	0.3	18.3	0.2
284	1883-8-2-586	Song	Xining yuanbao CL	-	-	1 cash	1068	3.34	XRFA	74.3	10.9	<0.1	13.8	<0.1
285	Edkins E78	Song	Xining yuanbao ST	-	-	1 cash	1068	4.19	XRFU	59	15.6	0.4	24.1	0.3
286	1883-8-2-581	Song	Xining yuanbao ST	-	-	1 cash	1068	3.77	XRFA	66.9	12.7	<0.1	20.2	<0.1
287	1882-6-1-178	Song	Xining yuanbao ST	-	-	1 cash	1068	3.72	result unreliable					

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
288	1883-8-2-588	Song	Xining yuanbao ST	-	-	1 cash	1068	3.13	XRFU	70	10.2	0.3	19.1	0.2
289	1870-5-7-14627	Song	Xining yuanbao CU	-	-	1 cash	1068	3.11	XRFU	77	10.9	0.4	11.2	0.3
290	1883-8-2-589	Song	Xining yuanbao CU	-	-	1 cash	1068	4.31	XRFA	69.3	10.1	<0.1	20.4	0.1
291	General Coll. GC216	Song	Xining yuanbao SE	-	-	1 cash	1068	2.33	XRFU	65	7.9	0.3	26.5	0.2
292	Edkins E78	Song	Xining yuanbao SE	-	-	1 cash	1068	4.13	XRFA	66	8.9	<0.1	24.8	<0.1
293	1883-8-2-570	Song	Xining yuanbao SE	-	-	1 cash	1068	5.06	XRFU	66	12.2	0.4	21	0.2
294	General Coll. GC200	Song	Xining yuanbao SE	-	-	1 cash	1068	4.1	XRFA	66	12.5	<0.1	21.2	<0.1
295	General Coll. GC203	Song	Xining yuanbao SE	-	-	1 cash	1068	4.3	XRFU	73	12.7	0.5	13.4	0.2
296	1870-5-7-14620	Song	Xining yuanbao SE	-	-	1 cash	1068	4.15	XRFA	66	8.5	<0.1	24.9	0.5
297	1887-5-11-183	Song	Xining yuanbao SE	-	-	1 cash	1068	3.84	XRFU	59	15	0.2	24.9	0.6
298	General Coll. GC205	Song	Xining yuanbao SE	-	-	1 cash	1068	2.55	XRFU	67	11.8	0.3	18.9	2
299	1883-8-2-575	Song	Xining yuanbao SE	-	-	1 cash	1068	4.78	XRFU	70	9.9	0.4	18.1	1.8
300	1883-8-2-574	Song	Xining yuanbao SE	-	-	1 cash	1068	4.43	XRFU	64	10.6	0.7	24.5	0.3
301	1897-12-7-7	Song	Xining zhongbao ST	-	-	2 cash	1068	7.06	XRFA	70.4	7.3	<0.1	22.2	<0.1
302	General Coll. GC212	Song	Xining zhongbao ST	-	-	2 cash	1068	8.41	XRFU	71	8.5	0.2	20.3	0.4
303	Miscellaneous M74	Song	Xining zhongbao ST	-	-	2 cash	1068	6.06	XRFU	55	26.1	0.3	8.8	9.8
304	1887-5-11-147	Song	Xining zhongbao ST	-	-	2 cash	1068	8.24	XRFA	68.8	11.6	<0.1	19.2	<0.1
305	1883-8-2-144	Song	Xining zhongbao SE	-	-	2 cash	1068	7.98	XRFA	77.8	3.8	<0.1	18.4	<0.1
306	1883-8-2-593	Song	Xining zhongbao SE	-	-	2 cash	1068	5.95	XRFU	79	7	0.2	13.5	0.3
307	1884-5-11-1110	Song	Yuanfeng tongbao CU	-	-	2 cash	1068	6.28	XRFU	63	4.7	0.1	31.4	0.6
308	1883-8-2-615	Song	Yuanfeng tongbao CU	-	-	2 cash	1068	7.81	XRFA	73	4.2	<0.1	22.8	<0.1
309	Webster W20	Song	Yuanfeng tongbao SE	-	-	2 cash	1068	6.01	XRFA	70.4	5.5	<0.1	24.5	0.1
310	1886-10-6-799	Song	Yuanfeng tongbao SE	-	-	2 cash	1068	7.59	XRFU	60	6.1	<0.1	33.7	0.5
311	1870-5-7-14648	Song	Yuanfeng tongbao ST	-	Japanese copy	1 cash	1068	4.02	XRFU	46	1.2	<0.1	50.9	1.6
312	General Coll. GC220	Song	Yuanfeng tongbao ST	-	Japanese copy	1 cash	1068	3.56	XRFU	80.2	0.82	<0.1	17	2
313	1870-5-7-14634	Song	Yuanfeng tongbao CU	-	-	1 cash	1068	3.65	XRFA	70.4	9.6	<0.1	19.9	<0.1
314	General Coll. GC229	Song	Yuanfeng tongbao CU	-	-	1 cash	1068	4.13	XRFU	67	10.1	1.2	21.6	0.4
315	1884-5-11-1119	Song	Yuanfeng tongbao CU	-	Japanese copy	1 cash	1078	3.67	XRFU	73	0.2	<0.1	24	2.4
316	1884-5-11-1120	Song	Yuanfeng tongbao CU	-	Japanese copy	1 cash	1078	2.98	XRFU	76	1.9	0.2	3.9	18.1
317	Edkins E90	Song	Yuanfeng tongbao SE	-	-	1 cash	1068	3.38	XRFU	71	10.7	0.2	17.4	0.6
318	1883-8-2-599	Song	Yuanfeng tongbao SE	-	-	1 cash	1068	3.3	XRFA	64.2	9.7	<0.1	26	<0.1
319	Webster W21	Song	Yuanyou tongbao CU	-	-	2 cash	1093	9.06	XRFU	65.9	6.1	0.2	27.4	0.5
320	1883-8-2-630	Song	Yuanyou tongbao CU	-	-	2 cash	1093	6.3	XRFA	63	7.4	<0.1	29	<0.3
321	Heath H44	Song	Yuanyou tongbao SE	-	-	2 cash	1093	7.13	XRFA	69.6	3.7	<0.1	26.9	0.1
322	1883-8-2-627	Song	Yuanyou tongbao SE	-	-	2 cash	1093	7.84	XRFU	64	11.2	0.1	23.7	1.1
323	1870-5-7-14652	Song	Yuanyou tongbao CU	-	-	1 cash	1093	3.64	XRFU	70	9.1	0.3	20.1	0.6
324	Edkins E95	Song	Yuanyou tongbao CU	-	-	1 cash	1093	4.63	XRFA	71.9	9.2	<0.1	19.7	0.1
325	1908-6-5-130	Song	Yuanyou tongbao SE	-	-	1 cash	1093	3.26	XRFU	69	7	0.2	23.7	0.4
326	Heath H41	Song	Yuanyou tongbao SE	-	-	1 cash	1093	3.76	XRFA	69.1	9.2	<0.1	21.5	0.1
327	Miscellaneous M46	Song	Shaosheng yuanbao CU	-	-	1 cash	1094	3.94	XRFU	66	12.6	0.3	19.6	1.1
328	1908-6-5-90	Song	Shaosheng yuanbao CU	-	-	1 cash	1094	3.36	XRFA	68.5	10.6	<0.1	20.3	0.3
329	Kingdom K35	Song	Shaosheng yuanbao SE	-	-	1 cash	1094	3.38	XRFA	65.1	11.2	<0.1	23.1	0.1
330	1870-5-7-14667	Song	Shaosheng yuanbao SE	-	-	1 cash	1094	3.8	XRFU	47	18.2	<0.1	34.4	0.3
331	1883-8-2-658	Song	Yuanfu tongbao CU	-	-	1 cash	1098	3.6	XRFA	69.1	7	<0.1	22.8	0.1
332	1883-8-2-657	Song	Yuanfu tongbao CU	-	-	1 cash	1098	3.94	XRFU	75	8.1	0.4	16.5	0.2
333	1882-6-1-216	Song	Yuanfu tongbao SE	-	-	1 cash	1098	3.08	XRFA	67.7	9.8	0.4	21.4	0.3
334	1908-6-5-51	Song	Yuanfu tongbao SE	-	-	1 cash	1098	3.21	XRFU	71	8.4	0.2	20.1	0.3
335	1883-8-2-670	Song	Shengsong yuanbao CU	-	-	1 cash	1101	3.51	XRFA	65.1	11.4	<0.1	23.3	0.1

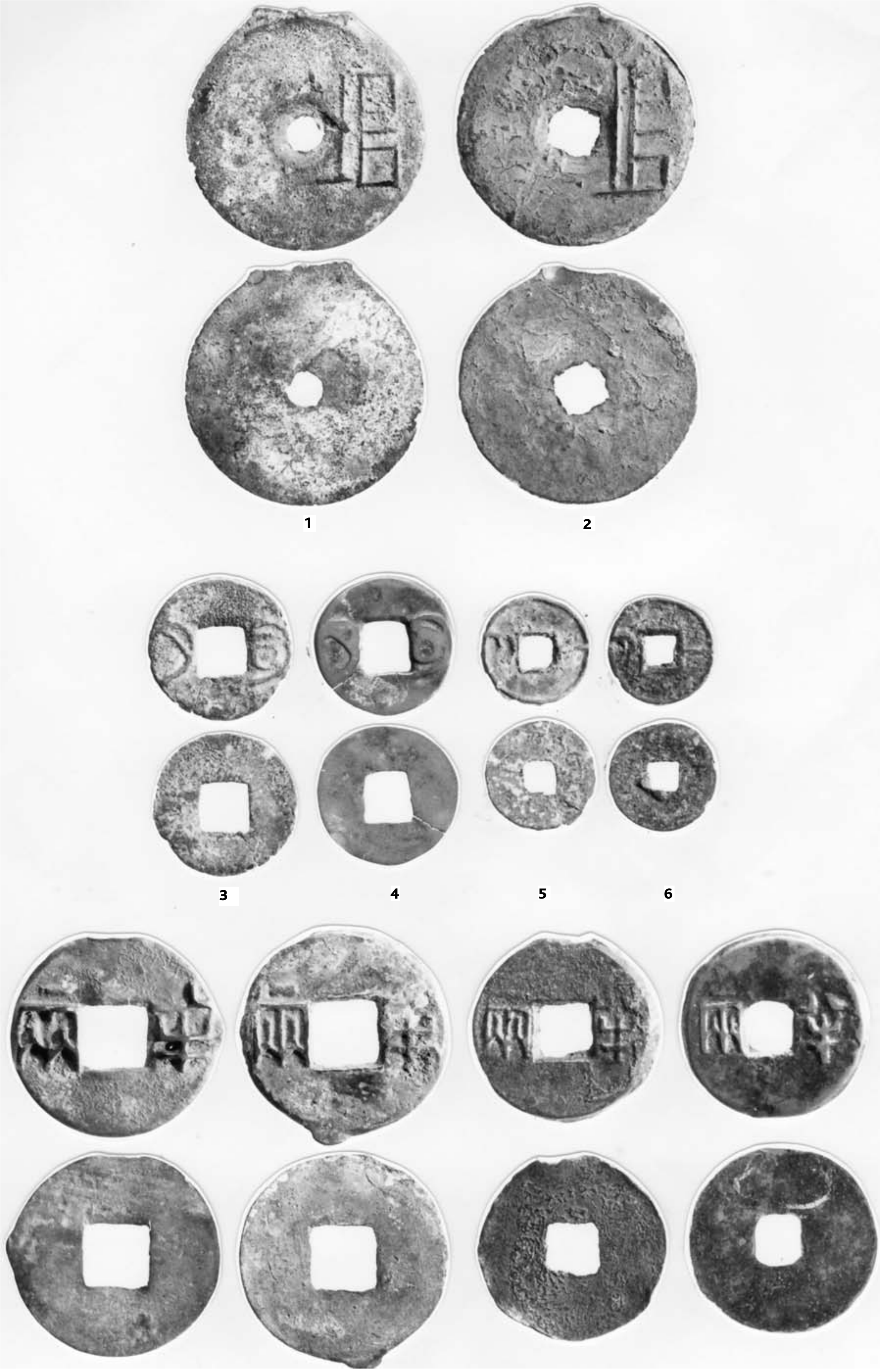
No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
336	1884-5-11-1206	Song	Shengsong yuanbao CU	-	-	1 cash	1101	3.18	XRFU	67	14.5	0.1	18	0.5
337	Edkins E106	Song	Shengsong yuanbao SE	-	-	1 cash	1101	3.88	XRFA	64.4	11	<0.1	24.1	<0.1
338	General Coll. GC270	Song	Shengsong yuanbao SE	-	-	1 cash	1101	3.26	XRFU	71.4	12.8	0.4	15.2	0.3
339	1882-6-1-228	Song	Chongning tongbao ST	-	-	10 cash	1102	10.08	XRFU	68	6.4	<0.1	25	0.8
340	General Coll. GC285	Song	Chongning tongbao ST	-	-	10 cash	1102	11.04	XRFA	72.7	5.1	<0.3	21.9	0.1
341	1870-5-7-14678	Song	Chongning zhongbao CL	-	-	10 cash	1104	8.55	XRFU	81	6.1	<0.1	13.1	0.2
342	1870-5-7-14679	Song	Chongning zhongbao CL	-	-	10 cash	1104	10.79	XRFA	68.6	8.8	<0.1	22.2	0.1
343	1883-8-2-683	Song	Chongning tongbao ST	-	-	1 cash	1102	3.11	XRFA	75	4.6	<0.3	20.1	<0.1
344	1883-8-2-682	Song	Chongning tongbao ST	-	-	1 cash	1102	3.61	XRFU	57	7	1	34.2	0.6
345	1870-5-7-14684	Song	Daguan tongbao ST	-	-	10 cash	1107	17.47	XRFU	78	6.6	<0.1	15.2	0.3
346	1882-6-1-233	Song	Daguan tongbao ST	-	-	10 cash	1107	17.2	XRFU	78	6.2	<0.1	15.9	0.2
347	1883-8-2-700	Song	Daguan tongbao ST	-	-	1 cash	1107	3.27	XRFU	68	7.7	0.2	23.4	1.1
348	General Coll. GC287	Song	Daguan tongbao ST	-	-	1 cash	1107	3.38	XRFA	69.6	8.8	<0.1	21.3	0.1
349	1884-5-11-1168	Song	Daguan tongbao ST	-	[Japanese copy ?]	1 cash	1107	4.05	XRFU	63	6.8	0.1	28.1	2.3
350	1884-5-11-1179	Song	Daguan tongbao ST	-	[Japanese copy ?]	1 cash	1107	2.88	XRFA	67.5	15.2	<0.1	16.4	0.1
351	1884-5-11-1174	Song	Daguan tongbao ST	-	[Japanese copy ?]	1 cash	1107	2.57	XRFU	80.1	7.5	0.1	12.2	0.2
352	1870-5-7-14690	Song	Zhenghe tongbao SE	-	-	2 cash	1111	5.48	XRFU	63	7.7	0.1	27.1	1.7
353	Edkins E114	Song	Zhenghe tongbao SE	-	-	2 cash	1111	8.36	XRFU	66	5.5	<0.1	27.5	0.5
354	Edkins E118	Song	Zhenghe tongbao CL	-	-	1 cash	1111	2.96	XRFU	54	24.2	2	14.9	4.7
355	General Coll. GC300	Song	Zhenghe tongbao CL	-	-	1 cash	1111	3.91	XRFA	61.3	9.9	<0.1	27.9	0.5
356	Miscellaneous M197	Song	Zhenghe tongbao SE	-	-	1 cash	1111	2.45	XRFU	74	8.9	0.2	16.5	0.2
357	1908-6-5-41	Song	Zhenghe tongbao SE	-	-	1 cash	1111	3.61	XRFA	68.9	5	<0.1	24.3	1.7
358	1882-6-1-236	Song	Zhenghe tongbao CL	-	-	1 cash	1111	3.38	XRFA	72.6	8	<0.1	18.3	0.9
359	1908-6-5-43	Song	Zhenghe tongbao CL	-	-	1 cash	1111	3.22	XRFA	69.2	4.5	<0.1	26	0.1
360	Heath H53	Song	Zhonghe tongbao CL	-	-	1 cash	1118	3.07	XRFA	72	11.3	0.2	14.8	1.2
361	1882-6-1-244	Song	Xuanhe tongbao CL	-	-	2 cash	1119	6.28	XRFU	71	7	<0.1	20.4	1.2
362	1883-8-2-722	Song	Xuanhe tongbao CL	-	-	2 cash	1119	6.08	XRFA	67	10.6	<0.1	21.4	0.7
363	1883-8-2-725	Song	Xuanhe tongbao CL	-	-	2 cash	1119	6.73	XRFA	67.9	3.5	<0.1	27.3	1.1
364	1882-6-1-246	Song	Xuanhe tongbao CL	-	-	2 cash	1119	6.8	XRFU	57	18.1	0.2	20.7	4.4
365	1870-5-7-14693	Song	Xuanhe tongbao SE	-	-	2 cash	1119	7.18	XRFA	66.9	9.1	<0.1	23.2	0.4
366	Miscellaneous M199	Song	Xuanhe tongbao SE	-	-	2 cash	1119	5.58	XRFU	63	10.6	0.1	23.7	2.4
367	1883-8-2-715	Song	Xuanhe tongbao SE	-	-	1 cash	1119	3.64	XRFA	67.8	7.3	<0.1	23.7	0.9
368	1882-6-1-243	Song	Xuanhe tongbao SE	-	-	1 cash	1119	3.81	XRFU	71	15.8	0.1	11.8	1.4
369	Heath H57	Song	Jianyan tongbao ST	-	-	2 cash	1127	5.71	XRFA	69	16.9	<0.1	12.4	1.1
370	1882-6-1-259	Song	Jianyan tongbao ST	-	-	2 cash	1127	6.6	XRFU	64	7	<0.1	27.4	1.3
371	1882-6-1-257	Song	Jianyan tongbao SE	-	-	2 cash	1127	4.92	XRFA	71.2	8.3	<0.1	18.5	0.8
372	1883-8-2-751	Song	Jianyan tongbao SE	-	-	2 cash	1127	6.36	XRFU	60	15	<0.1	22.4	2.7
373	1883-8-2-767	Song	Shaoxing yuanbao	-	-	2 cash	1131	6.35	XRFU	58	10.7	<0.1	30.6	0.2
374	Edkins E128	Song	Shaoxing yuanbao	-	-	2 cash	1131	4.79	XRFU	42	23	<0.05	30.5	5
375	1883-8-2-758	Song	Shaoxing yuanbao	-	-	2 cash	1131	6.14	XRFA	63.5	10.9	<0.1	23.6	1
376	1883-8-2-757	Song	Shaoxing yuanbao	-	-	2 cash	1131	6.41	XRFU	65	6.9	<0.1	26.1	1.6
377	1882-6-1-265	Song	Shaoxing tongbao	-	-	2 cash	1131	6.03	XRFU	54	7.5	<0.1	37.5	1.2
378	1882-6-1-264	Song	Shaoxing tongbao	-	-	2 cash	1131	5.85	XRFA	70.5	10.8	<0.1	18.4	<0.1
379	1882-6-1-273	Song	Longxing yuanbao	-	-	2 cash	1163	7.62	XRFU	51	7.5	<0.1	39.6	2
380	Chinese Sup. CH50	Song	Longxing yuanbao	-	-	2 cash	1163	6.11	XRFA	84	9.1	<0.1	6.2	0.1
381	Heath H62	Song	Longxing yuanbao	-	-	2 cash	1163	6.39	XRFA	56.8	16.3	<0.1	24.9	1.6
382	Miscellaneous M219	Song	Longxing yuanbao	-	-	2 cash	1163	7.38	XRFU	41	10.6	<0.1	45	3.2
383	Miscellaneous M220	Song	Qiandao yuanbao	-	-	2 cash	1165	6.17	XRFU	75	4.1	<0.1	20.7	0.46

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
384	1883-8-2-784	Song	Qiandao yuanbao	-	-	2 cash	1165	5.36	XRFA	65.7	4.1	<0.1	28.9	0.9
385	1882-6-1-285	Song	Chunxi yuanbao	-	-	2 cash	1174	7.05	XRFU	73	4	<0.1	21.4	1.5
386	1882-6-1-286	Song	Chunxi yuanbao	-	-	2 cash	1174	6.07	XRFA	62.6	5.6	<0.1	31	0.5
387	1883-8-2-839	Song	Shaoxi yuanbao	-	-	2 cash	1190	7.89	XRFU	42.4	6.2	<0.1	47.9	3.6
388	1882-6-1-299	Song	Shaoxi yuanbao	-	-	2 cash	1190	8.62	XRFA	56.3	3.5	<0.1	38.6	1.3
389	1882-6-1-307	Song	Qingyuan tongbao	yuan	-	2 cash	1195	6.44	XRFA	71.6	4.2	<0.1	23.2	0.8
390	Heath H91	Song	Qingyuan tongbao	yuan	-	2 cash	1195	7.1	XRFU	68	2.4	0.3	27.7	1.9
391	1883-8-2-892	Song	Jiatai yuanbao	yuan	-	2 cash	1201	6.63	XRFA	64.7	1.2	<0.1	32.5	0.8
392	1882-6-1-319	Song	Jiatai yuanbao	yuan	-	2 cash	1201	6.52	XRFU	58	1.8	<0.1	38.1	1.8
393	1883-8-2-907	Song	Kaixi tongbao	yuan	-	2 cash	1205	4.75	XRFA	55	1.5	<0.1	41.3	0.8
394	1882-6-1-326	Song	Kaixi tongbao	yuan	-	2 cash	1205	5.64	XRFU	56	1.8	<0.1	39.6	2.5
395	1882-6-1-336	Song	Jiading tongbao	yuan	-	2 cash	1208	6.1	XRFA	62.7	0.7	<0.1	34	1.2
396	1883-8-2-918	Song	Jiading tongbao	yuan	-	2 cash	1208	5.63	XRFU	43	2.2	<0.1	50.6	3.9
397	General Coll. GC329	Song	Dasong yuanbao	yuan	-	2 cash	1225	5.94	XRFA	67.8	4.1	<0.1	27.1	0.75
398	1883-8-2-974	Song	Dasong yuanbao	yuan	-	2 cash	1225	8.04	XRFU	66	2.7	<0.1	28.8	2.6
399	1882-6-1-353	Song	Shaoding tongbao	yuan	-	2 cash	1228	7.55	XRFU	62	2.4	0.3	33.1	2.3
400	1883-8-2-979	Song	Shaoding tongbao	yuan	-	2 cash	1228	7.13	XRFU	42	7.2	0.2	47.5	3.1
401	Webster W46	Song	Jiaxi tongbao	yuan	-	2 cash	1237	5.36	XRFA	62.1	2.3	<0.1	34.1	1.2
402	Heath H130	Song	Jiaxi tongbao	yuan	-	2 cash	1237	7.61	XRFA	62	1.7	<0.1	34.8	1.1
403	General Coll. GC332	Song	Chunyou yuanbao	yuan	-	2 cash	1241	6.63	XRFU	69	3.2	0.3	26.4	1.3
404	1882-6-1-362	Song	Chunyou yuanbao	yuan	-	2 cash	1241	4.95	XRFA	65.1	1.9	<0.1	31.4	1
405	Webster W47	Song	Huangsong yuanbao	yuan	-	2 cash	1235	6.73	XRFA	68	2.9	<0.1	27.7	0.8
406	Heath H141	Song	Huangsong yuanbao	yuan	-	2 cash	1235	6.49	XRFA	61	4.4	<0.1	33	1.5
407	1882-6-1-375	Song	Jingding yuanbao	yuan	-	2 cash	1260	6.7	XRFA	74	2.8	<0.1	22	1.8
408	1883-8-2-1055	Song	Jingding yuanbao	yuan	-	2 cash	1260	6.28	XRFA	64	2.2	<0.1	32	1.6
409	1882-6-1-379	Song	Xianchun yuanbao	yuan	-	2 cash	1265	4.88	XRFA	74	3.9	0.1	20	2.2
410	Heath H152	Song	Xianchun yuanbao	yuan	-	2 cash	1265	4.82	XRFA	63	3.2	<0.1	32	1.8
411	Heath H156	Song	Xianchun yuanbao	ba	-	2 cash	1272	4.78	XRFA	62	3.1	<0.1	32	2.5
412	1883-8-2-1109	Jin	Dading tongbao	yu	-	1 cash	1189	3.28	XRFU	75	18	0.1	6.4	0.5
413	1882-6-1-392	Jin	Dading tongbao	yu	-	1 cash	1189	3.91	XRFA	75.5	17.3	<0.1	6.6	0.1
414	1883-8-2-1127	Yuan	Zhida tongbao	-	-	1 cash	1310	4.19	XRFA	74.5	11.6	0.5	13	0.1
415	1908-6-5-98	Yuan	Zhida tongbao	-	-	1 cash	1310	3.9	XRFU	83	7.1	0.1	9.3	0.2
416	1964-2-23-1	Yuan	Zhizheng tongbao	chen	-	1 cash	1352	3.25	XRFU	71	10	<0.1	17	0.3
417	1884-5-11-2133	Yuan	Zhizheng tongbao	chen	-	1 cash	1352	3.37	XRFA	73.2	8.6	<0.1	17.9	<0.3
418	1882-6-1-415	Ming	Dazhong tongbao	-	-	1 cash	1361	3.22	XRFU	57	15	0.3	27	0.2
419	1886-10-6-784	Ming	Dazhong tongbao	-	-	1 cash	1361	2.87	XRFA	70.5	11.3	<0.1	17.9	0.1
420	1882-6-1-419	Ming	Hongwu tongbao	-	-	1 cash	1368	3.25	XRFA	75	9.5	0.1	15	0.3
421	1883-8-2-1173	Ming	Hongwu tongbao	-	-	1 cash	1368	2.65	XRFA	74	8.2	0.1	18	0.4
422	1883-8-2-1193	Ming	Hongwu tongbao	fu	Fuzhou	1 cash	1368	3.03	XRFA	76	9.5	0.1	14	0.7
423	1870-5-7-14717	Ming	Hongwu tongbao	fu	Fuzhou	1 cash	1368	2.65	XRFA	75	7.3	0.1	17	1.1
424	1883-8-2-1185	Ming	Hongwu tongbao	bei ping	Beijing	1 cash	1368	3.77	XRFA	78	7	0.1	15	0.2
425	1883-8-2-1181	Ming	Hongwu tongbao	bei ping	Beijing	1 cash	1368	3.13	XRFA	76	9.2	0.7	13	1.4
426	1883-8-2-1201	Ming	Yongle tongbao	-	-	1 cash	1408	3.97	XRFA	73	8.5	0.1	18	0.2
427	1882-6-1-443	Ming	Yongle tongbao	-	-	1 cash	1408	3.36	XRFA	72	8	0.1	19	0.7
428	1882-6-1-447	Ming	Xuande tongbao	-	-	1 cash	1433	3.89	XRFA	78	7.6	0.1	14	0.9
429	1908-6-5-34	Ming	Xuande tongbao	-	-	1 cash	1433	3.62	XRFA	73	9.3	0.3	16	1.1
430	General Coll. GC 374	Ming	Xuande tongbao	-	-	1 cash	1433	3.675	AAS	-	8.2	<0.01	18.5	0.18
431	1882-6-1-445	Ming	Xuande tongbao	-	-	1 cash	1433	2.792	XRFA	77	8	1.5	14	0.31

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
432	1979-2-27-121	Ming	Xuande tongbao	-	-	1 cash	1433	3.7969	AAS	-	8.6	0.02	13.5	0.21
433	1978-9-19-199	Ming	Xuande tongbao	-	-	1 cash	1433	4.055	AAS	66.6	7.5	0.04	22.9	0.17
434	Heath H181	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	3.56	AAS	-	9.8297	1.2336	2.8224	0.54
435	1883-8-2-1205	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	2.82	XRFA	87.1	8.5	0.41	3.7	0.13
436	1870-5-7-14722	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	4.15	AAS	-	10.083	0.0627063	11.65	0.21
437	1870-5-7-14723	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	2.96	XRFA	79.3	7.6	0.45	12.4	0.05
438	1883-8-2-1204	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	3.752	AAS	-	7.7	0.96	11.6	0.03
439	1979-3-3-72	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	3.419	XRFA	82	16	0.7	0.6	0.08
440	1974-5-14-69	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	5.093	AAS	-	10.6	<0.01	14.8	<0.05
441	Webster W52	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	3.839	AAS	-	3.7	0.22	15.7	0.05
442	1887-5-11-190	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	3.206	XRFA	85	10	1.7	2.8	0.23
443	1882-6-1-450	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	4.278	AAS	-	8.5	<0.01	16.2	0.06
444	1882-6-1-451	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	2.277	XRFA	81	10	1.6	7	0.14
445	Webster W53	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	3.746	AAS	-	6.7	<0.01	23	0.09
446	1883-8-2-1206	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	6.458	AAS	-	10.7	1.2	6.8	0.14
447	Edkins E174	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	3.346	AAS	-	10.9	1.3	4.1	0.17
448	1882-6-1-452	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	4.241	AAS	-	10.8	1	4.9	0.39
449	1982-11-31-57	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	2.644	XRFA	72	9.3	<0.1	17.8	0.11
450	1979-3-4-22	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	2.75	XRFA	69	7.8	13.3	9.6	0.04
451	Rhodes Coll. not BM	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	-	XRFU	65.5	7.4	16.2	10.9	<0.2
452	1975-9-29-2	Ming	Hongzhi tongbao	-	-	1 cash	1503-5	2.433	XRFA	77	5	<0.1	17.2	0.03
453	Miscellaneous M257	Ming	Jiajing tongbao	-	-	1 cash	1527-70	3.11	AAS	-	6.9	22.7	7	0.06
454	1882-6-1-458	Ming	Jiajing tongbao	-	-	1 cash	1527-70	2.94	AAS	-	7.3906	17.828	5.1864	0.36
455	General Coll. GC378	Ming	Jiajing tongbao	-	-	1 cash	1527-70	2.86	XRFA	60	7.5	16.4	14.4	0.92
456	1883-8-2-1225	Ming	Jiajing tongbao	-	-	1 cash	1527-70	3.73	XRFA	69.1	7.4	13	8.5	2
457	1883-8-2-1224	Ming	Jiajing tongbao	-	-	1 cash	1527-70	4.12	AAS	-	3.988	13.547	0.72144	0.52
458	1886-10-6-791	Ming	Jiajing tongbao	-	-	1 cash	1527-70	3.79	AAS	-	3.2298	12.522	0.81988	0.08
459	1883-8-2-1222	Ming	Jiajing tongbao	-	-	1 cash	1527-70	3.78	XRFA	69.7	5.5	16.03	7.2	0.86
460	1882-6-1-460	Ming	Jiajing tongbao	-	-	1 cash	1527-70	3.87	XRFA	69.7	5.5	17.4	6.54	0.29
461	General Coll. GC379	Ming	Longqing tongbao	-	-	1 cash	1570-76	4.44	AAS	-	5.7541	19.529	3.034	0.23
462	1883-8-2-1226	Ming	Longqing tongbao	-	-	1 cash	1570-76	4.08	AAS	-	4.1427	22.594	2.9417	0.33
463	Edkins E177	Ming	Longqing tongbao	-	-	1 cash	1570-76	3.38	XRFA	67.7	6.3	19.4	3.2	3.4
464	1886-10-6-778	Ming	Longqing tongbao	-	-	1 cash	1570-76	3.71	XRFA	59.4	5.2	21.6	2.7	11.1
465	Miscellaneous M258	Ming	Wanli tongbao	-	-	1 cash	1576-1621	3.2794	XRFA	63	0.61	32.5	2.4	0.61
466	1870-5-7-14728	Ming	Wanli tongbao	-	-	1 cash	1576-1621	4.3944	XRFA	71.7	2.9	21.8	2.2	1.1
467	Miscellaneous M269	Ming	Wanli tongbao	-	-	1 cash	1576-1621	3.2941	XRFA	66.5	1.3	25.7	6.1	0.38
468	Miscellaneous M267	Ming	Wanli tongbao	-	-	1 cash	1576-1621	3.3599	XRFA	61.8	1.7	30.8	5.3	0.42
469	General Coll. GC382	Ming	Wanli tongbao	-	-	1 cash	1576-1621	4.2184	XRFA	69.5	0.1	27.6	1.9	0.53
470	1882-6-1-467	Ming	Wanli tongbao	-	-	1 cash	1576-1621	3.8057	XRFA	76.3	0.4	21.1	2	0.19
471	Miscellaneous M266	Ming	Wanli tongbao	-	-	1 cash	1576-1621	4.48	AAS	-	3.9589	22.74	4.5616	0.44
472	1882-6-1-479	Ming	Wanli tongbao	-	-	1 cash	1576-1621	3.63	AAS	-	1.4014	21.417	1.0967	1.25
473	Miscellaneous M268	Ming	Wanli tongbao	-	-	1 cash	1576-1621	4.14	AAS	-	2.4691	31.887	1.8342	0.28
474	1870-5-7-14731	Ming	Wanli tongbao	-	-	1 cash	1576-1621	3.7	AAS	-	2.9613	32.847	2.2415	0.25
475	Miscellaneous M262	Ming	Wanli tongbao	-	-	1 cash	1576-1621	3.92	XRFA	69.1	4.3	23.2	2.5	0.73
476	Miscellaneous M263	Ming	Wanli tongbao	-	-	1 cash	1576-1621	4.82	XRFA	78.6	3.7	13.6	3	0.79
477	1882-6-1-473	Ming	Wanli tongbao	gong	Public	1 cash	1576-1621	2.8	XRFA	70.4	2	13.7	11.2	2.5
478	1882-6-1-474	Ming	Wanli tongbao	gong	Public	1 cash	1576-1621	3.6	XRFA	76.1	5.7	6.94	10.5	0.47
479	1883-8-2-1252	Ming	Wanli tongbao	-	-	2 cash	1576-1621	4.91	AAS	-	8.0811	9.9459	8.2703	0.32

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
480	1883-8-2-1248	Ming	Wanli tongbao	-	-	2 cash	1576-1621	4.72	AAS	-	4.214	14.716	10.591	0.33
481	1870-5-7-14737	Ming	Tianqi tongbao	hu	Board of Revenue	1 cash	1621-28	4.1	AAS	-	0.86785	33.807	5.2268	0.41
482	1882-6-1-491	Ming	Tianqi tongbao	hu	Board of Revenue	1 cash	1621-28	3.07	XRFA	65.8	0.02	31.4	1.7	0.6
483	1886-10-6-697	Ming	Chongzhen tongbao	hu	Board of Revenue	1 cash	1628-46	2.86	AAS	-	0.1761	40.151	1.8164	0.5
484	Edkins E184	Ming	Chongzhen tongbao	hu	Board of Revenue	1 cash	1628-46	2.32	XRFA	54.6	0.11	36.9	6.3	1.7
485	Heath H195	Ming	Chongzhen tongbao	hu	Board of Revenue	1 cash	1628-46	3.25	AAS	-	-0.1387	40.832	0.32178	0.42
486	1883-8-2-1350	Ming	Chongzhen tongbao	hu	Board of Revenue	1 cash	1628-46	2.54	XRFA	62.8	0.05	36	0.66	0.32
487	1883-8-2-1541	Ming rebels	Liyong tongbao	yun	Yunnan?	1 cash	1674	4.58	XRFA	85.6	<0.1	11.1	3.2	0.14
488	Heath H237	Ming rebels	Liyong tongbao	yun	Yunnan?	1 cash	1674	4.11	XRFA	88.2	<0.1	9.6	1.8	0.37
489	1883-8-2-1540	Ming rebels	Liyong tongbao	yun	Yunnan?	1 cash	1674	4.19	XRFA	86.8	0.09	11.4	1.3	0.34
490	1883-7-1-468	Ming rebels	Liyong tongbao	yun	Yunnan?	1 cash	1674	4.1	XRFA	85.7	0.05	12.2	1.9	0.16
491	General Coll. GC417	Ming rebels	Liyong tongbao	yun	Yunnan?	1 cash	1674	5.7	XRFA	84.7	<0.1	12.9	2.1	0.23
492	1886-10-6-664	Qing	Shunzhi tongbao	yun, yi li	Yunnan	1 cash	1644-61	4.27	XRFA	84.2	0.25	9.9	3.6	0.33
493	1870-5-7-14785	Qing	Shunzhi tongbao	yun, yi li	Yunnan	1 cash	1644-61	4.09	XRFA	81.7	0.39	12.1	4.1	0.51
494	1882-6-1-616	Qing	Shunzhi tongbao	yun, yi li	Yunnan	1 cash	1644-61	3.89	XRFA	81.1	0.67	12.3	4.4	0.38
495	Miscellaneous M324	Qing	Shunzhi tongbao	yun, yi li	Yunnan	1 cash	1644-61	4.21	XRFA	82.8	0.34	11.4	3.8	0.34
496	1882-6-1-617	Qing	Shunzhi tongbao	yun, yi li	Yunnan	1 cash	1644-61	5.74	XRFA	84.3	0.26	9.7	3.9	0.38
497	Webster W97	Qing	Shunzhi tongbao	hu, yi li	Board of Revenue	1 cash	1653-7	4.13	AAS	-	1.6115	26.49	6.2031	0.55
498	1882-6-1-600	Qing	Shunzhi tongbao	hu, yi li	Board of Revenue	1 cash	1653-7	3.86	AAS	-	2.0887	24.378	6.7811	0.49
499	1883-8-2-1652	Qing	Shunzhi tongbao	hu	Board of Revenue	1 cash	1646-53	4.24	AAS	-	3.056	24.629	7.5038	0.54
500	1882-6-1-585	Qing	Shunzhi tongbao	hu	Board of Revenue	1 cash	1646-53	3.96	AAS	-	2.1042	21.833	8	0.42
501	1882-6-1-622	Qing	Shunzhi tongbao	boo ciowan	Board of Revenue	1 cash	1657-62	3.97	AAS	-	2.5834	21.141	8.3746	0.5
502	1882-6-1-624	Qing	Shunzhi tongbao	boo ciowan	Board of Revenue	1 cash	1657-62	4.21	XRFA	65	2.7	20.8	9.9	0.58
503	1976-1-12-3	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	4.22	AAS	-	1.751	21.907	6.8288	0.56
504	1975-9-29-39	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	4.95	AAS	-	1.7937	21.764	7.1898	0.54
505	1975-9-29-55	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	3.31	XRFA	60.9	1.2	29.8	6.7	0.87
506	1975-9-29-5	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	3.11	XRFA	60.5	1.3	30.4	6.4	0.88
507	1975-9-29-91	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	3.01	AAS	-	<0.1	35.633	1.2809	0.47
508	1975-9-29-92	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	2.77	XRFA	65.3	<0.1	33.9	0.71	0.07
509	1883-8-2-1862	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	2.63	XRFA	66	<0.1	33.1	0.7	0.09
510	1902-6-8-137	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	2.8	AAS	-	0.19074	36.621	1.0627	0.49
511	1975-9-29-112	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	2.79	AAS	-	0.91873	34.629	4.2403	1.31
512	1882-6-1-655	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	3.02	XRFA	63.3	<0.1	35.6	0.85	0.25
513	1975-9-29-118	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	4.45	AAS	-	0.15556	37.644	1.0222	0.76
514	General Coll. GC458	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	4.73	AAS	-	0.48015	34.608	2.0314	0.35
515	1882-6-1-731	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	4.89	AAS	-	0.1897	35.068	0.59621	1.6
516	1882-6-1-730	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	5.01	AAS	-	<0.1	36.771	0.89686	0.38
517	1975-9-29-96	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	3.54	XRFA	63.2	<0.1	35.7	0.67	0.33
519	Heath H271	Qing	Kangxi tongbao	yun	Yunnan	1 cash	1662-1722	4.71	XRFA	98.3	0.08	0.1	0.98	0.34
518	Miscellaneous M339	Qing	Kangxi tongbao	boo ciowan	Board of Revenue	1 cash	1662-1723	4.61	AAS	-	<0.1	41.076	0.58127	0.5
520	1883-8-2-1763	Qing	Kangxi tongbao	yun	Yunnan	1 cash	1662-1722	4.41	XRFA	90.5	0.08	7.1	2	0.22
521	1882-6-1-722	Qing	Kangxi tongbao	yun	Yunnan	1 cash	1662-1722	4.89	XRFA	89.3	0.4	5.4	3.6	0.3
522	1882-6-1-723	Qing	Kangxi tongbao	yun	Yunnan	1 cash	1662-1722	6.04	XRFA	84.5	0.3	9.3	4.1	0.35
523	General Coll. GC451	Qing	Kangxi tongbao	yun	Yunnan	1 cash	1662-1722	4.99	XRFA	96.1	0.1	2.4	0.85	0.15
524	1870-5-7-14846	Qing	Yongzheng tongbao	boo ciowan	Board of Revenue	1 cash	1723-35	5.09	AAS	-	<0.1	37.785	1.5309	0.28
525	Miscellaneous M388	Qing	Yongzheng tongbao	boo ciowan	Board of Revenue	1 cash	1723-35	4.14	XRFA	60.6	<0.1	37.4	1.5	0.31
526	Miscellaneous M389	Qing	Yongzheng tongbao	boo ciowan	Board of Revenue	1 cash	1723-35	4.23	AAS	-	<0.1	36.905	0.78869	0.39
527	1883-8-2-1911	Qing	Yongzheng tongbao	boo ciowan	Board of Revenue	1 cash	1723-35	4.08	XRFA	62.7	<0.1	35.7	1.1	0.29

No.	BM Reg no.	Period	Obverse	Reverse	Mint	Denom.	Date	Wt (g.)	Tech.	Cu	Sn	Zn	Pb	Fe
528	Miscellaneous M406	Qing	Yongzheng tongbao	boo yun	Yunnan	1 cash	1723-35	5.22	XRFA	60.9	1	28.1	8.9	0.32
529	1870-5-7-14855	Qing	Yongzheng tongbao	boo yun	Yunnan	1 cash	1723-35	5.34	XRFA	62.2	0.37	31.5	5.1	0.63
530	1883-8-2-1900	Qing	Yongzheng tongbao	boo yun	Yunnan	1 cash	1723-35	4.28	XRFA	64.8	<0.1	25.4	8.9	0.14
531	Miscellaneous M403	Qing	Yongzheng tongbao	boo yun	Yunnan	1 cash	1723-35	5.77	XRFA	58.3	0.05	33	8.2	0.16
532	Edkins E279	Qing	Yongzheng tongbao	boo yun	Yunnan	1 cash	1723-35	4.88	XRFA	63.6	<0.1	31.8	4.3	0.24
533	1882-6-1-759	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.13	AAS	-	<0.1	36.526	0.82363	1.36
534	1882-6-1-760	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.48	AAS	-	<0.1	39.208	0.54665	0.47
535	1870-5-7-14868	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.57	XRFA	60.1	3	29.6	6.6	0.4
536	1882-6-1-763	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	3.96	XRFA	56.8	2.1	32.4	7.8	0.31
537	1882-6-1-766	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.78	AAS	-	1.677	33.602	6.5528	0.43
538	Miscellaneous M417	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.92	AAS	-	1.73	33.966	7.5316	0.51
539	1882-6-1-781	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.37	AAS	-	1.4079	32.44	6.9431	1.76
540	Miscellaneous M415	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	3.89	XRFA	59.1	1.9	32.1	4.5	1.2
541	1882-6-1-789	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.3	AAS	-	1.922	35.699	3.2921	0.59
542	1870-5-7-14871	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.54	AAS	-	1.9171	33.299	7.6684	1.12
543	1882-6-1-771	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.24	XRFA	54.3	1.5	35.7	5.7	1.6
544	1882-6-1-773	Qing	Qianlong tongbao	boo ciowan	Board of Revenue	1 cash	1736-95	4.16	AAS	54.38	1.4599	34.161	5.9854	2.5547
545	1883-8-2-2081	Qing	Jiaqing tongbao	boo ciowan	Board of Revenue	1 cash	1796-1820	4.13	XRFA	58	0.05	36	3.6	1.3
546	1886-10-6-736	Qing	Jiaqing tongbao	boo ciowan	Board of Revenue	1 cash	1796-1820	3.64	AAS	56.452	<0.2	34.274	4.543	0.84409
547	General Coll. GC597	Qing	Jiaqing tongbao	boo ciowan	Board of Revenue	1 cash	1796-1820	4.15	AAS	60.541	<0.9	33.405	3.3514	1.0054
548	1882-6-1-956	Qing	Jiaqing tongbao	boo ciowan	Board of Revenue	1 cash	1796-1820	4.47	XRFA	55.7	1.13	33.7	7.3	1.12
549	1883-7-1-38	Qing	Daoguang tongbao	boo ciowan	Board of Revenue	1 cash	1821-50	4.72	XRFA	60.3	0.03	33	3.7	0.89
550	1883-8-2-2155	Qing	Daoguang tongbao	boo ciowan	Board of Revenue	1 cash	1821-50	4.48	AAS	59.603	<0.3	33.212	3.2781	1.3146
551	1870-5-7-14966	Qing	Daoguang tongbao	boo ciowan	Board of Revenue	1 cash	1821-50	3.85	XRFA	56.6	0.03	33.1	5.8	1.57
552	Webster W129	Qing	Daoguang tongbao	boo ciowan	Board of Revenue	1 cash	1821-50	4.4	AAS	59.552	<0.3	31.704	3.7866	1.6179
553	1883-8-2-2228	Qing	Xianfeng tongbao	boo ciowan	Board of Revenue	1 cash	1851-62	3.47	XRFA	54.5	0	35.9	6.3	1.7
554	Edkins E334	Qing	Xianfeng tongbao	boo ciowan	Board of Revenue	1 cash	1851-62	4.34	AAS	56.877	<0.3	36.914	3.1599	1.8216
555	1870-5-7-14998	Qing	Xianfeng tongbao	boo ciowan	Board of Revenue	1 cash	1851-62	4.44	XRFA	55.6	0.03	34.7	5.8	1.8
556	1886-10-6-722	Qing	Xianfeng tongbao	boo ciowan	Board of Revenue	1 cash	1851-62	3.97	XRFA	55.5	0.01	36.8	5.2	1.7
557	1883-7-1-150	Qing	Xianfeng tongbao	boo ciowan	Board of Revenue	1 cash	1851-62	4.12	XRFU	-0.1	<0.1	98.7	0.7	0.7
558	1887-5-11-145	Qing	Xianfeng zhongbao	boo ciowan	Board of Revenue	10 cash	1851-62	12.57	XRFU	0.8	<0.1	97	0.9	1
559	1883-7-1-180	Qing	Tongzhi tongbao	boo ciowan	Board of Revenue	1 cash	1862-75	12.72	AAS	-	1.4465	36.478	4.261	1.6
560	1883-8-2-2381	Qing	Tongzhi tongbao	boo ciowan	Board of Revenue	1 cash	1862-75	13.21	AAS	-	0.10598	40.273	1.8471	3
561	1976-9-16-1	Qing	Guangxu tongbao	boo ciowan	Board of Revenue	1 cash	1875-1908	3.92	XRFA	57.3	0.15	36.5	4.7	0.68
562	1976-9-16-9	Qing	Guangxu tongbao	boo ciowan	Board of Revenue	1 cash	1875-1908	3	XRFA	52	0.28	40.8	4.8	1.7
563	1976-9-16-3	Qing	Guangxu tongbao	boo ciowan	Board of Revenue	1 cash	1875-1908	2.39	XRFA	57.3	0.53	32.8	6.5	2.1
564	1976-9-16-2	Qing	Guangxu tongbao	boo ciowan	Board of Revenue	1 cash	1875-1908	2.49	XRFA	57.2	0.43	33.9	5.5	1.8
565	1975-11-22-6	Qing	Xuantong tongbao	boo ciowan	Board of Revenue	1 cash	1909	2.29	XRFA	56.2	0.31	34.6	6.3	1.8
566	1976-9-16-36	Qing	Xuantong tongbao	boo ciowan	Board of Revenue	1 cash	1909	2.08	XRFA	56.1	0.31	35.7	5.3	1.8
567	1975-11-22-5	Qing	Xuantong tongbao	boo ciowan	Board of Revenue	1 cash	1909	2.23	XRFA	56.3	0.28	35.6	4.7	2.2
568	1975-11-22-4	Qing	Xuantong tongbao	boo ciowan	Board of Revenue	1 cash	1909	2.36	XRFA	56.9	0.37	34.1	5.9	1.8



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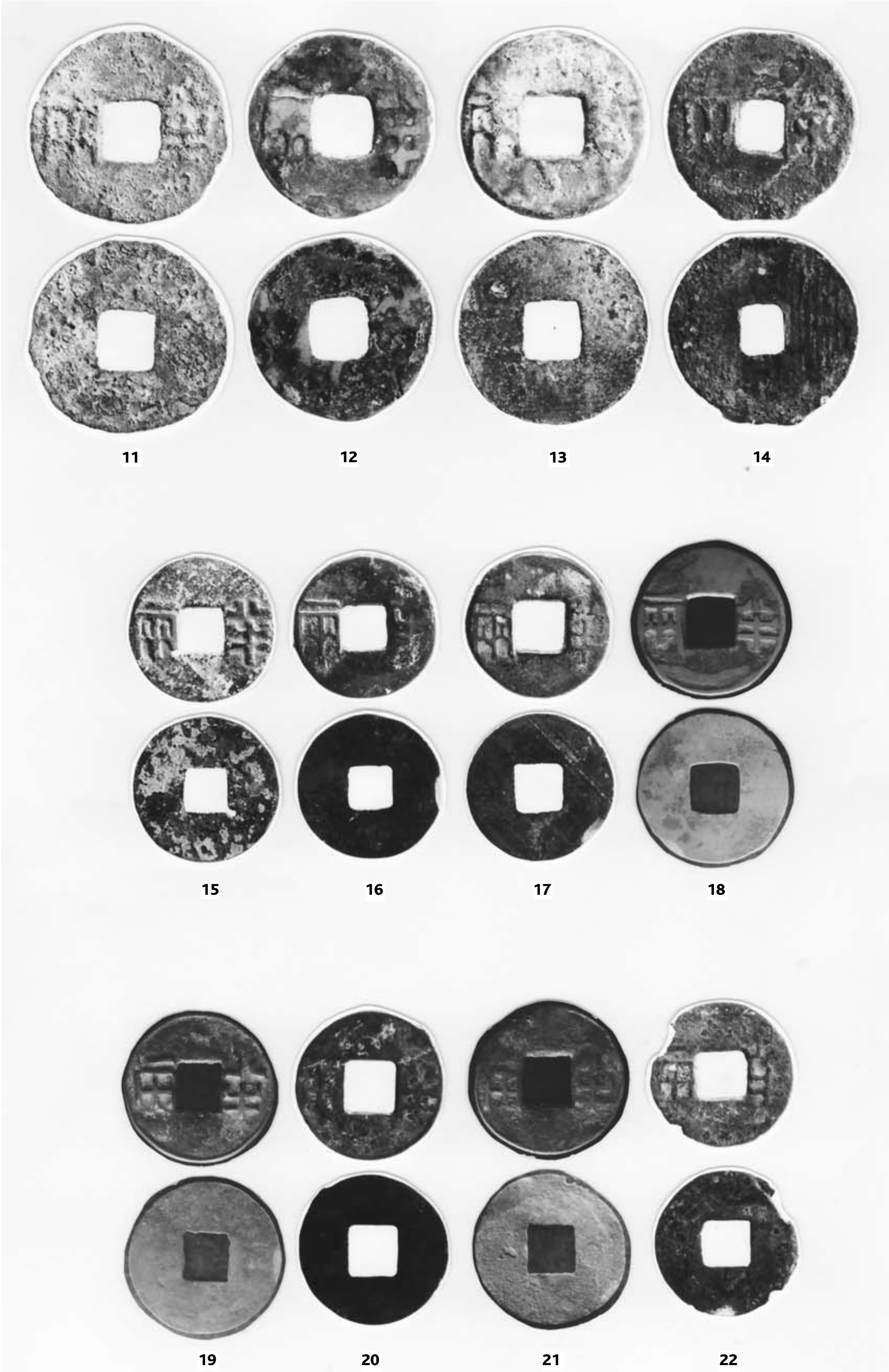
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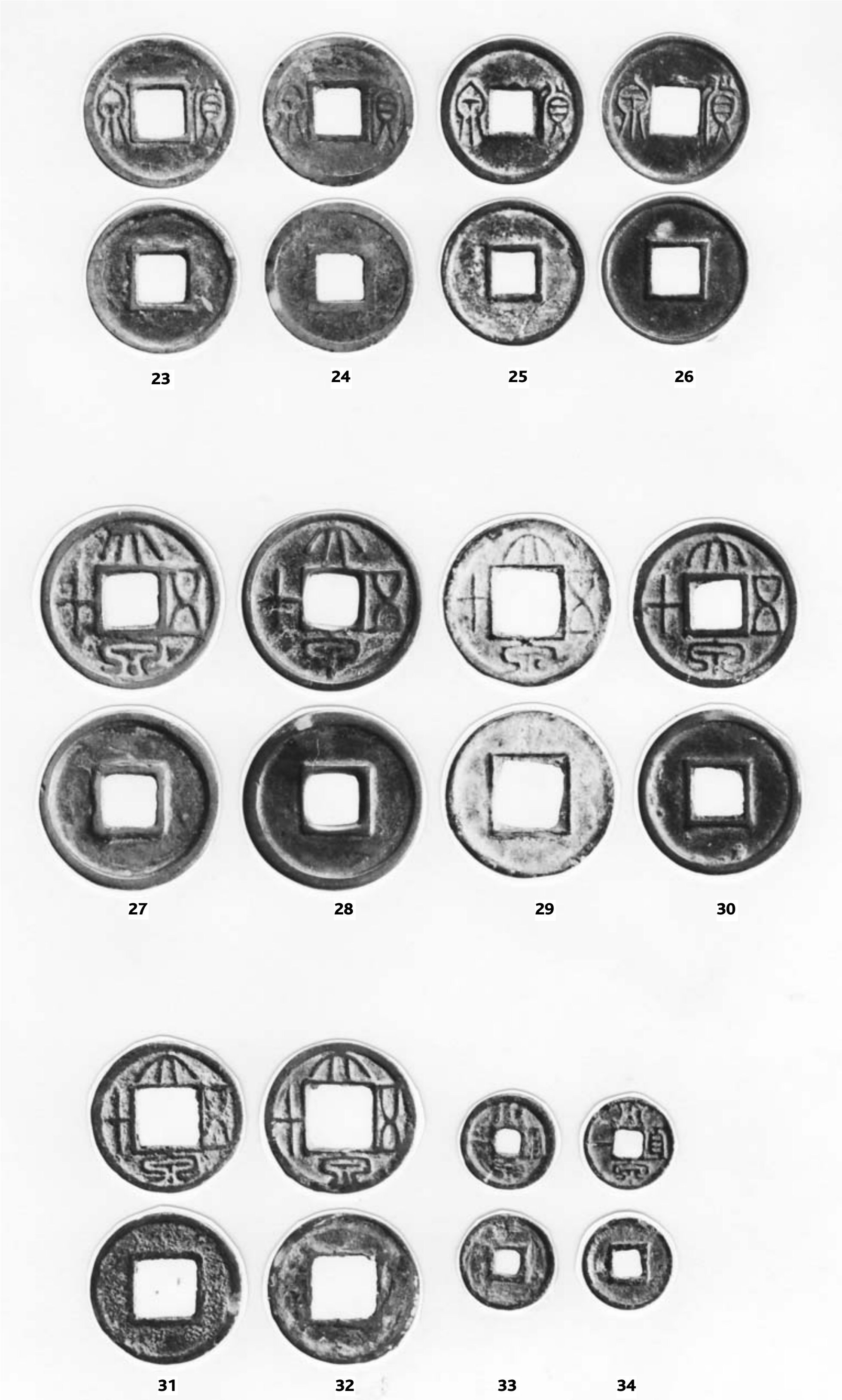

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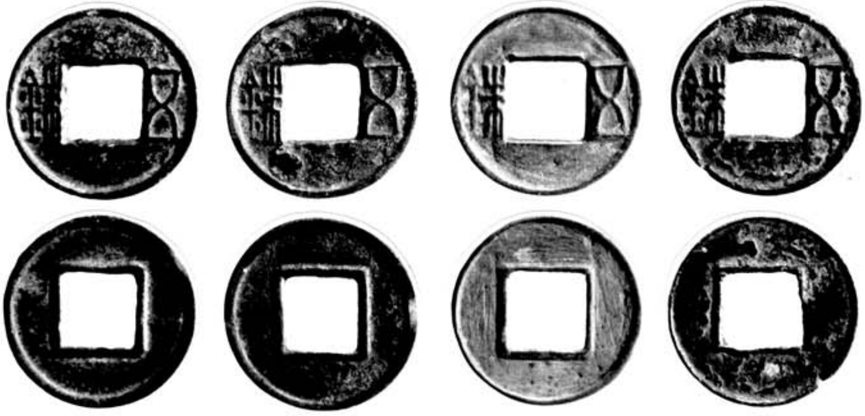

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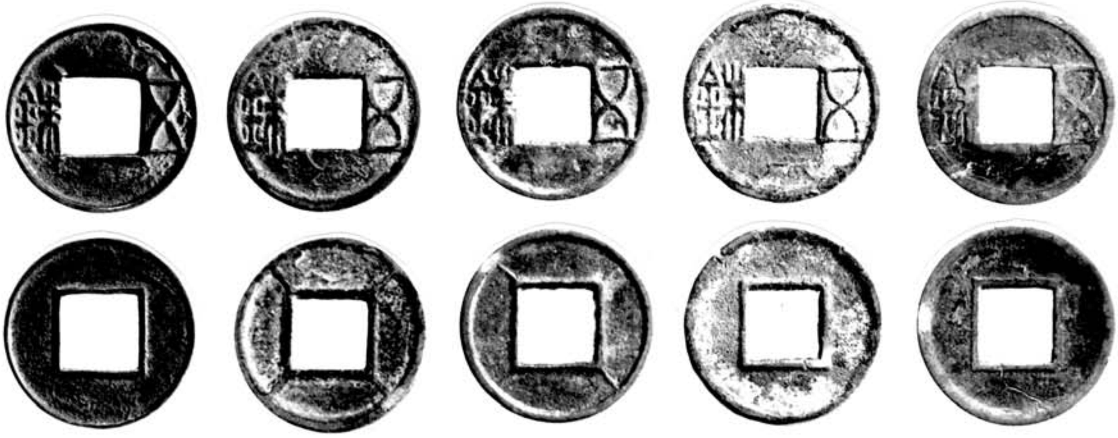

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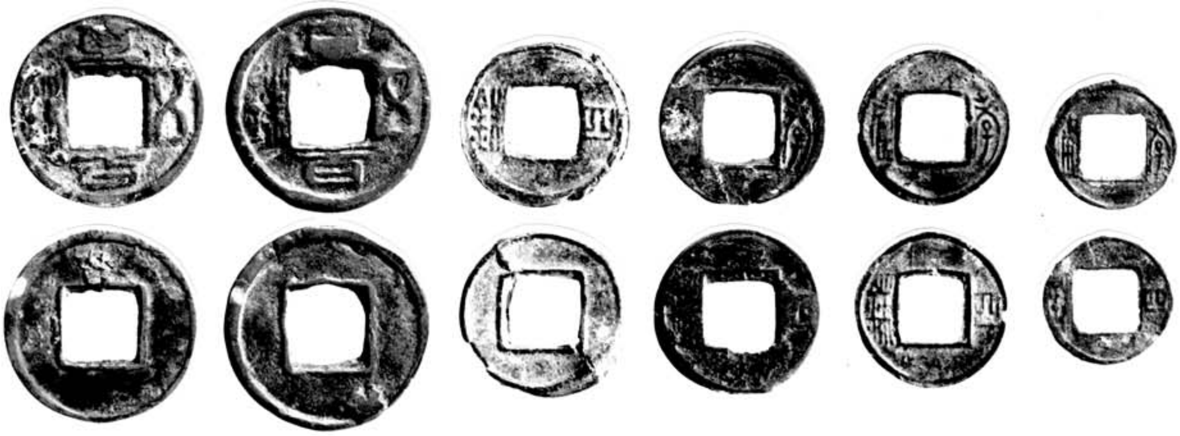

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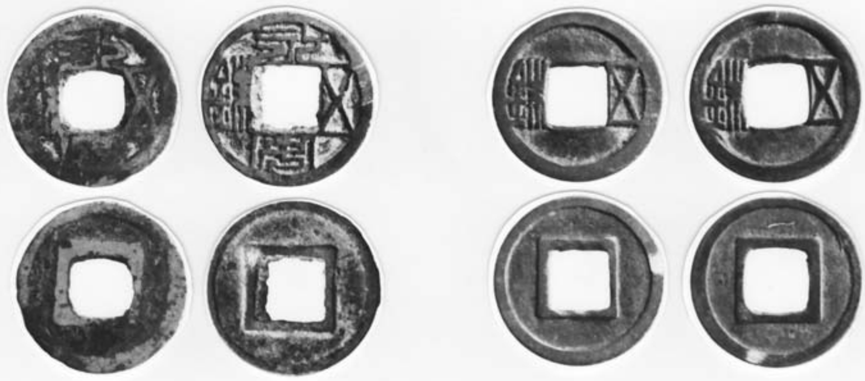

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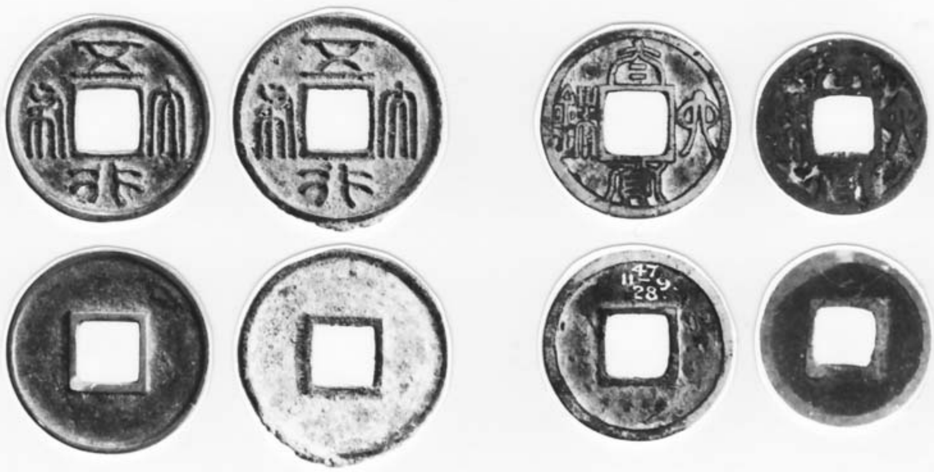

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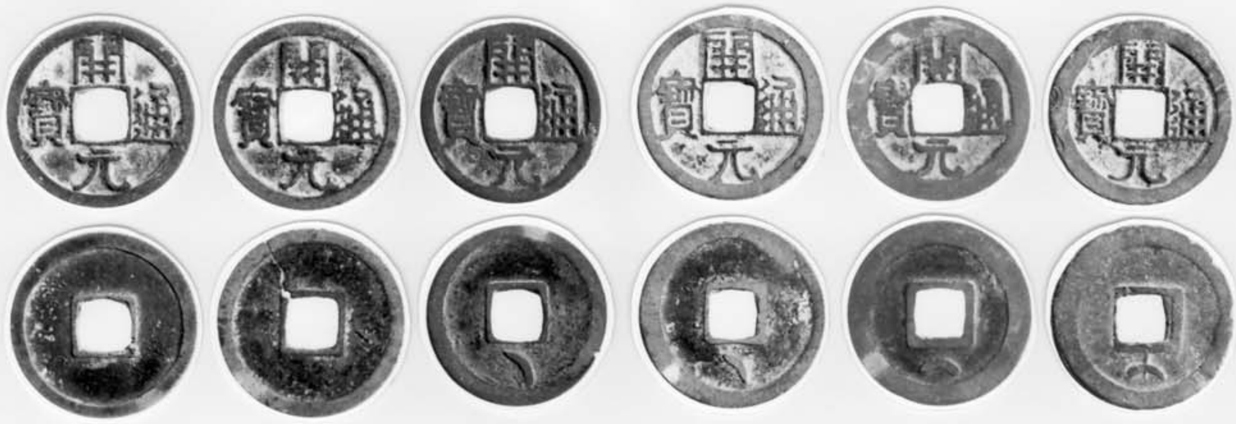

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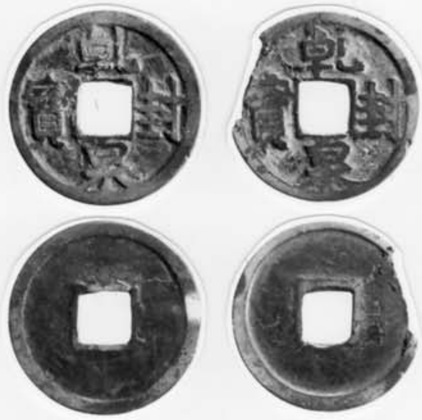

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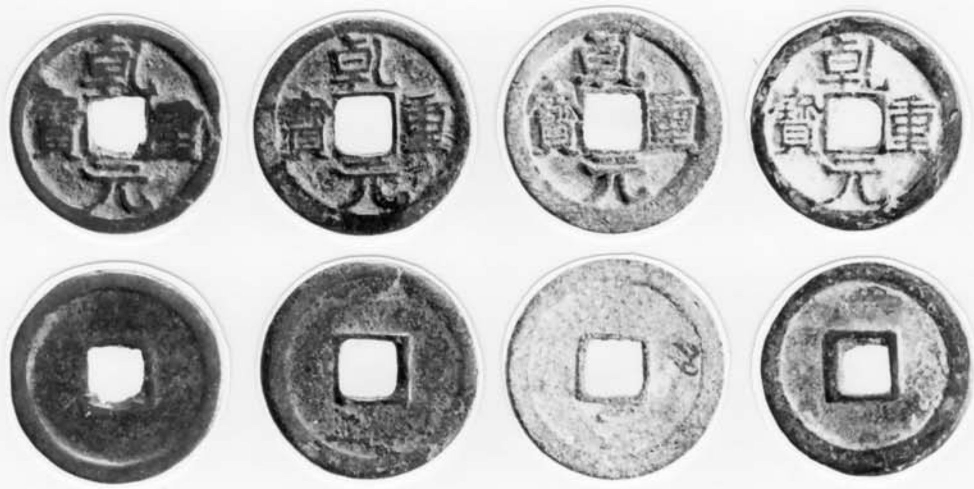

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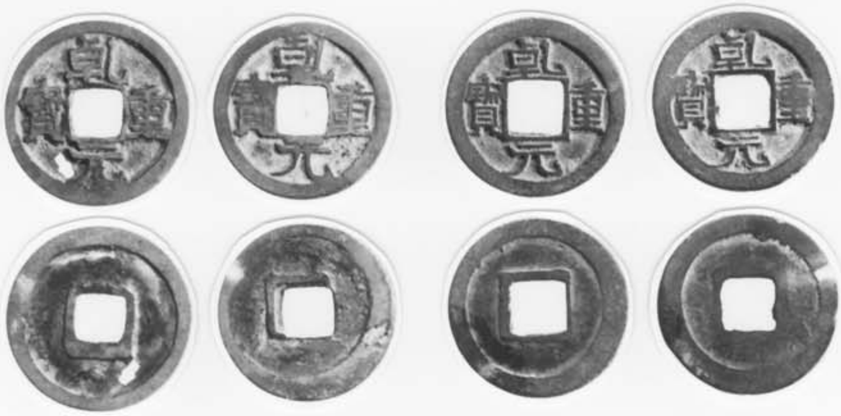

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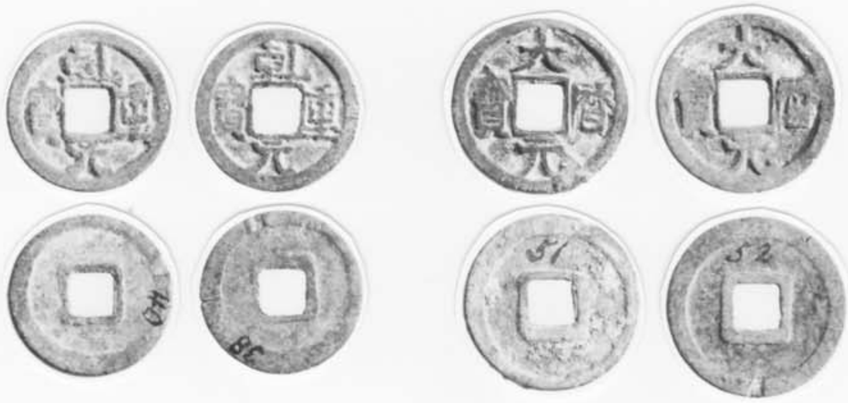

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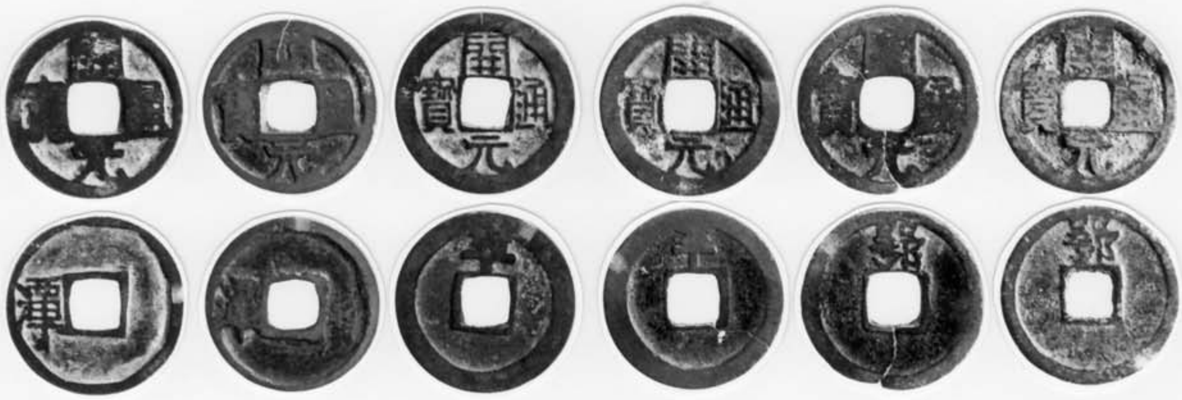

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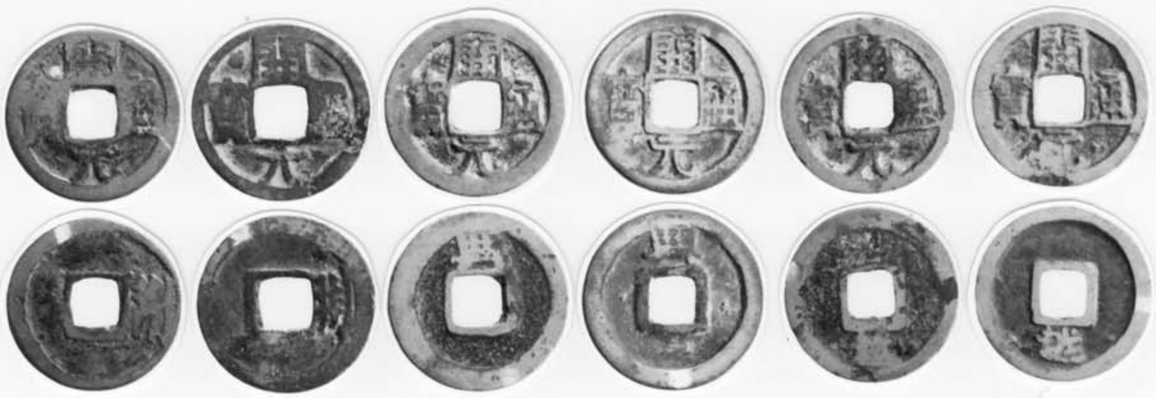

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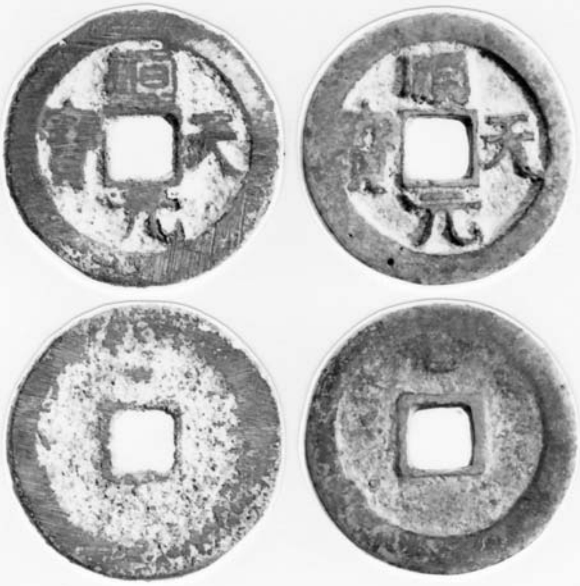

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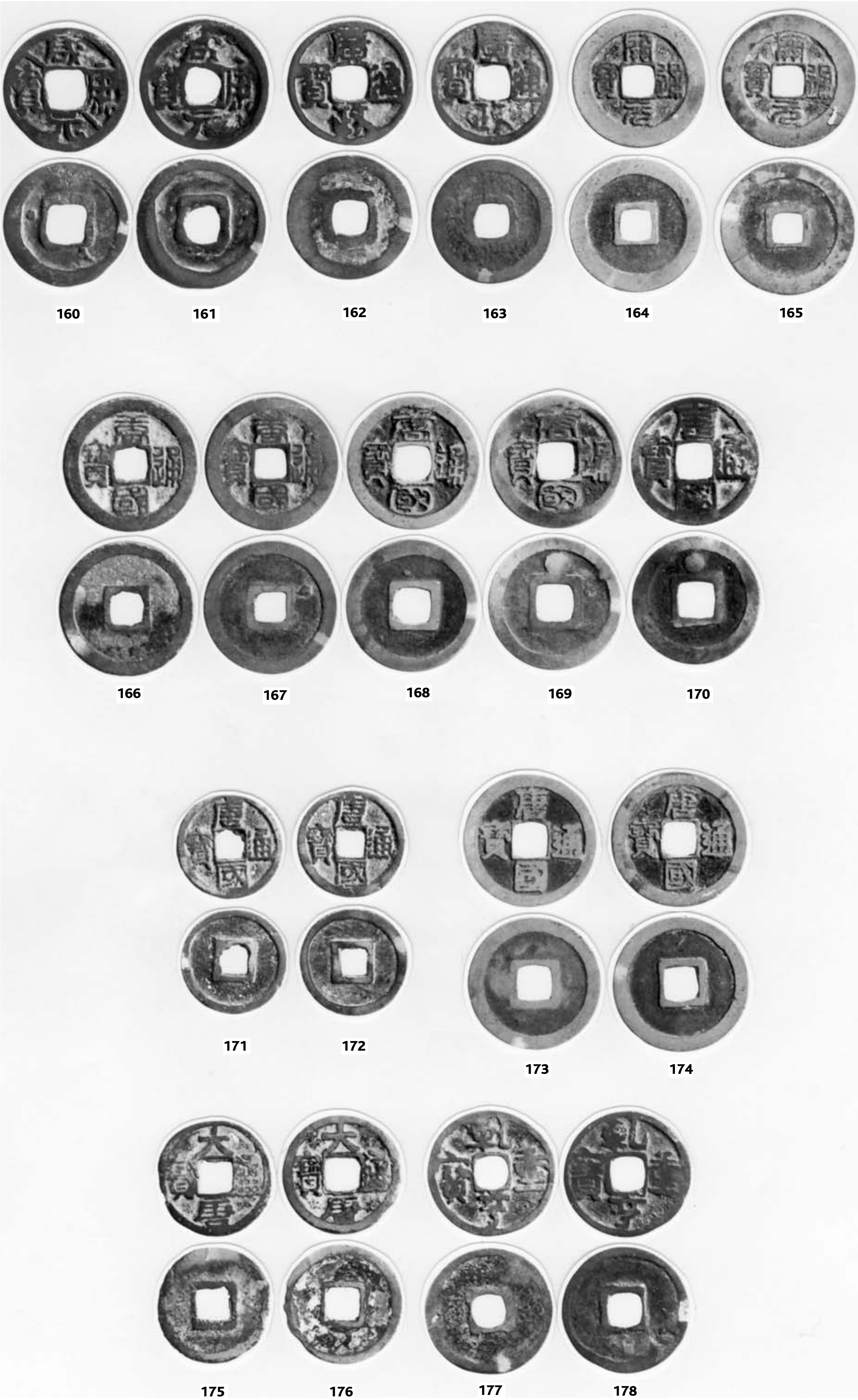
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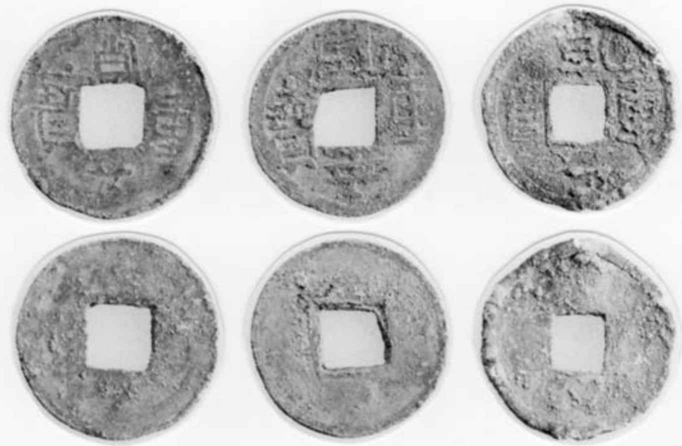

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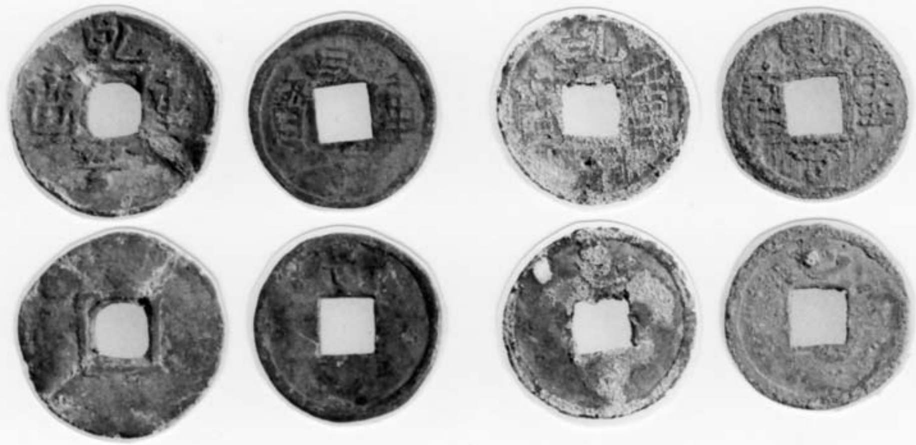

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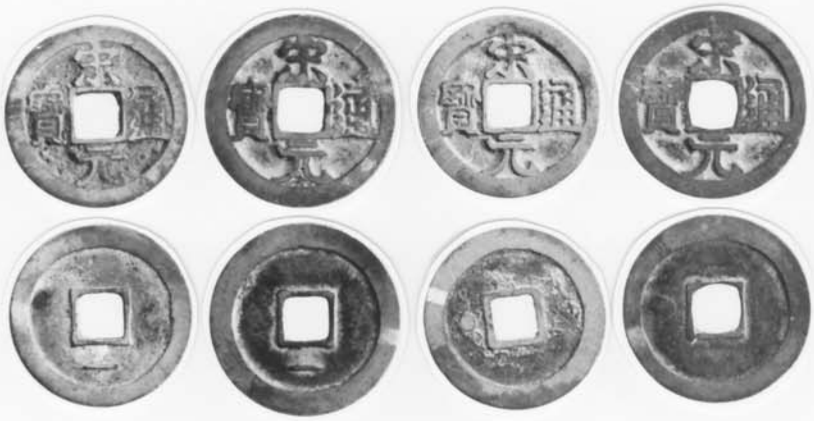

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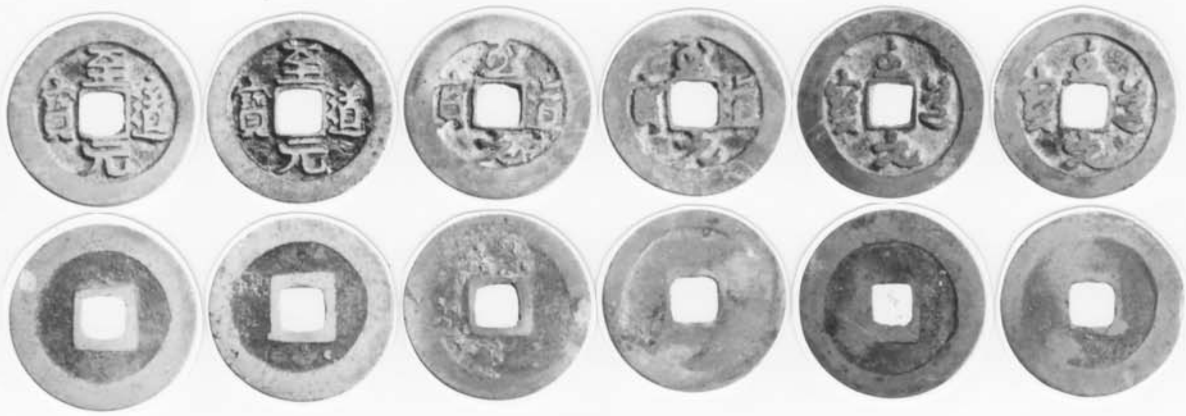

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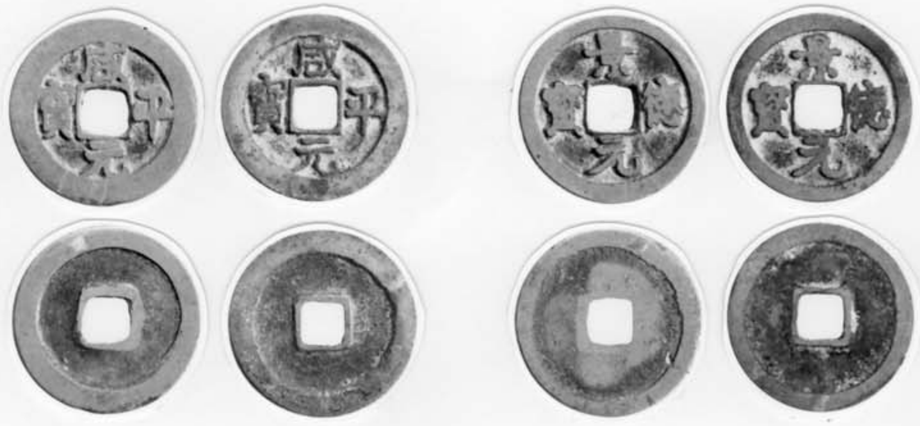

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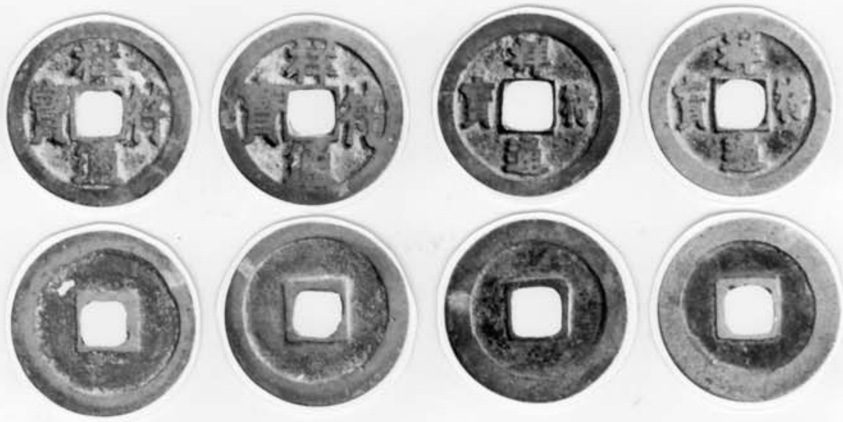

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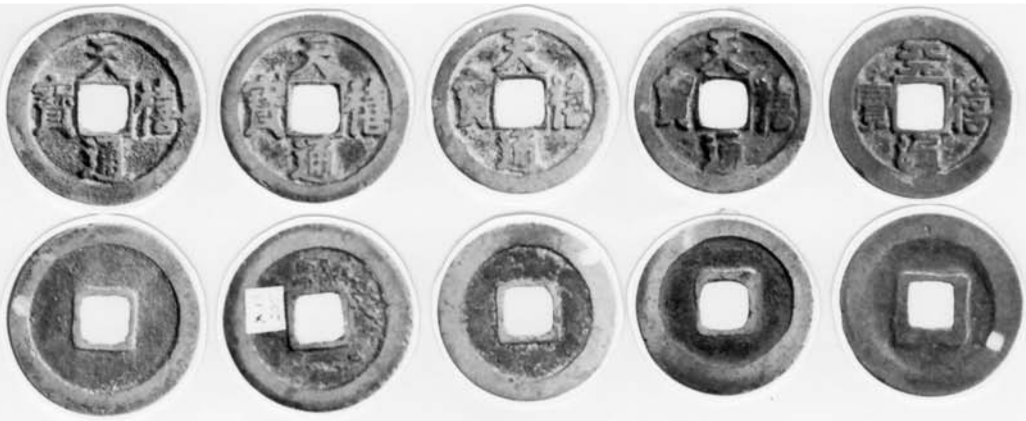

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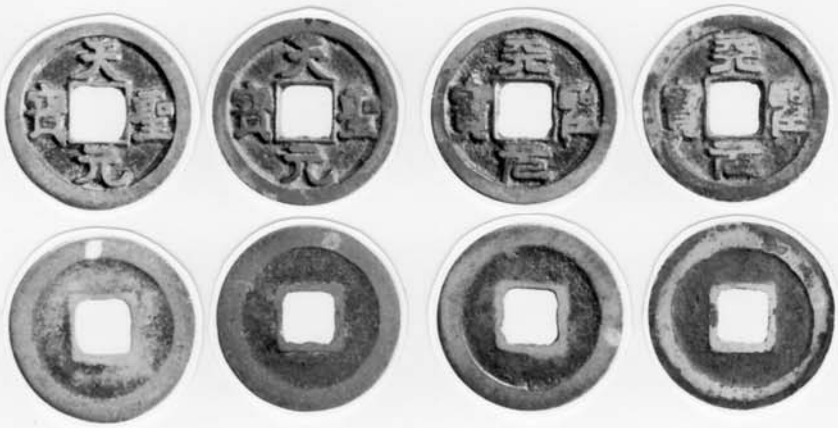

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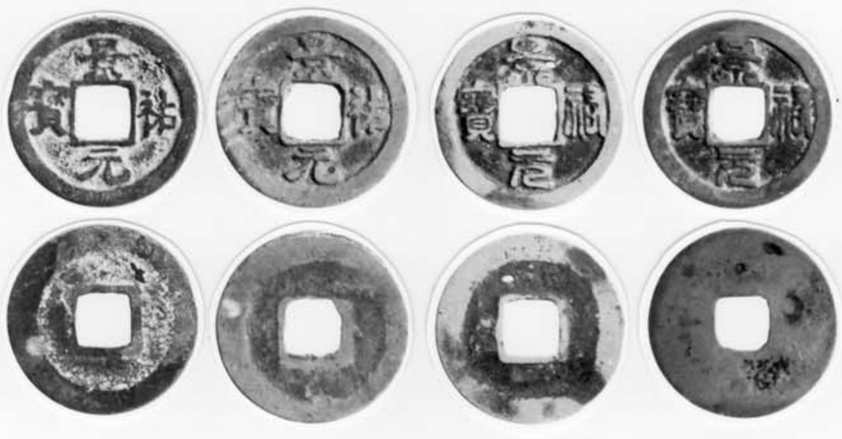

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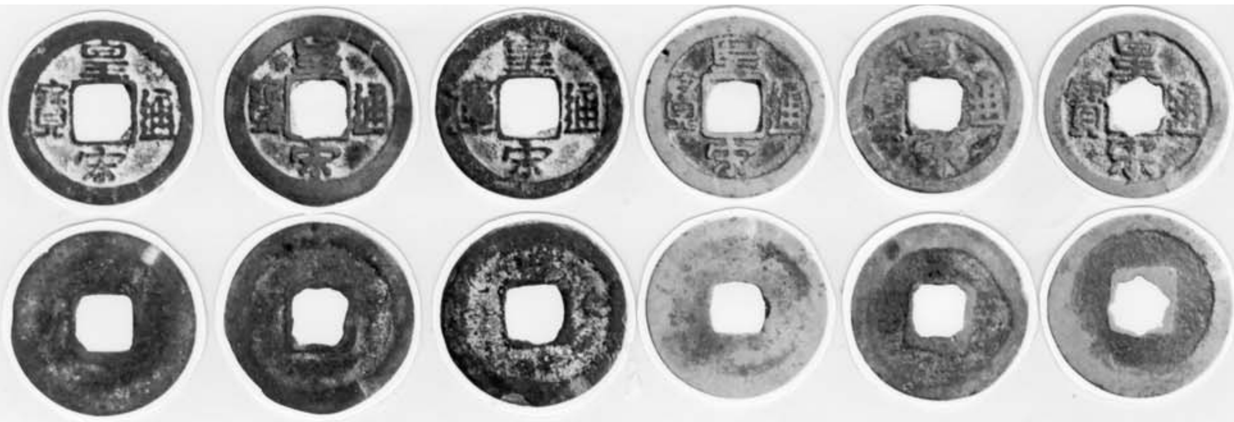

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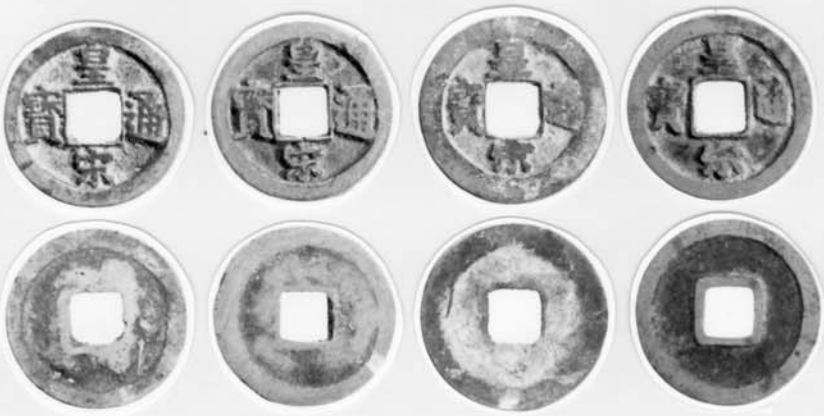

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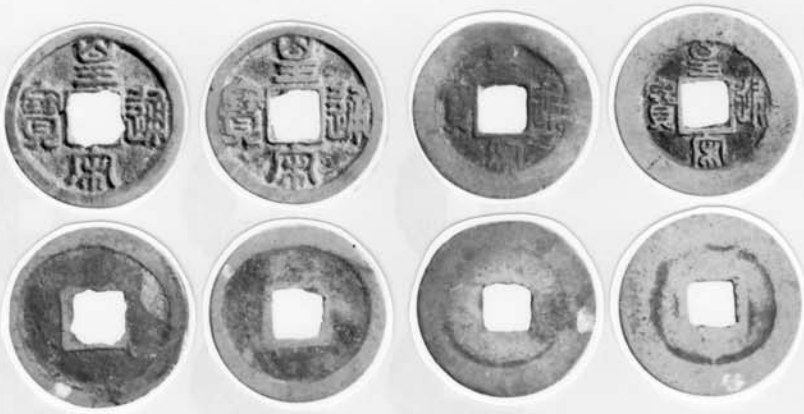

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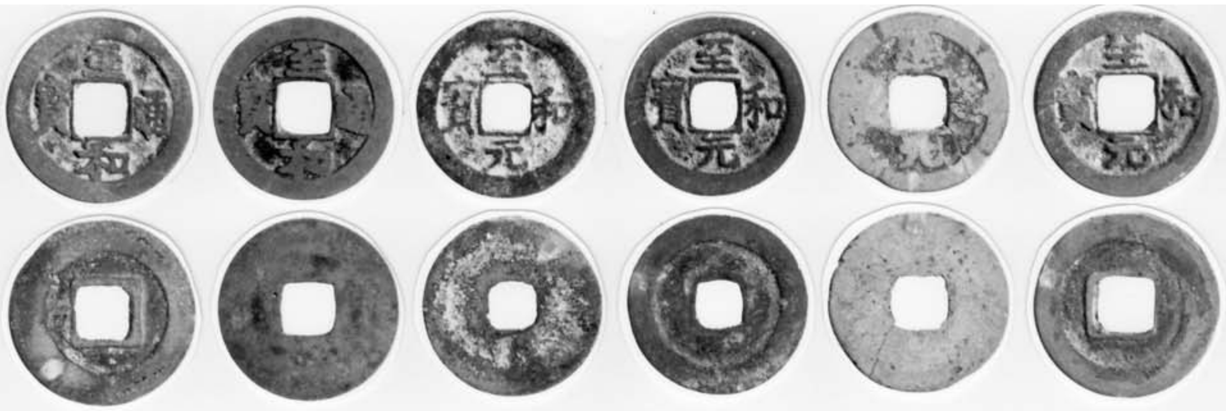

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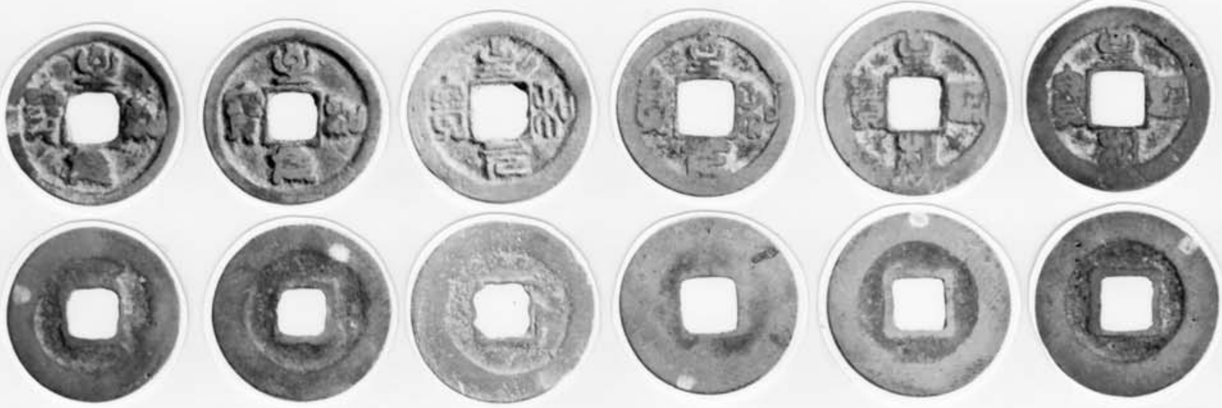

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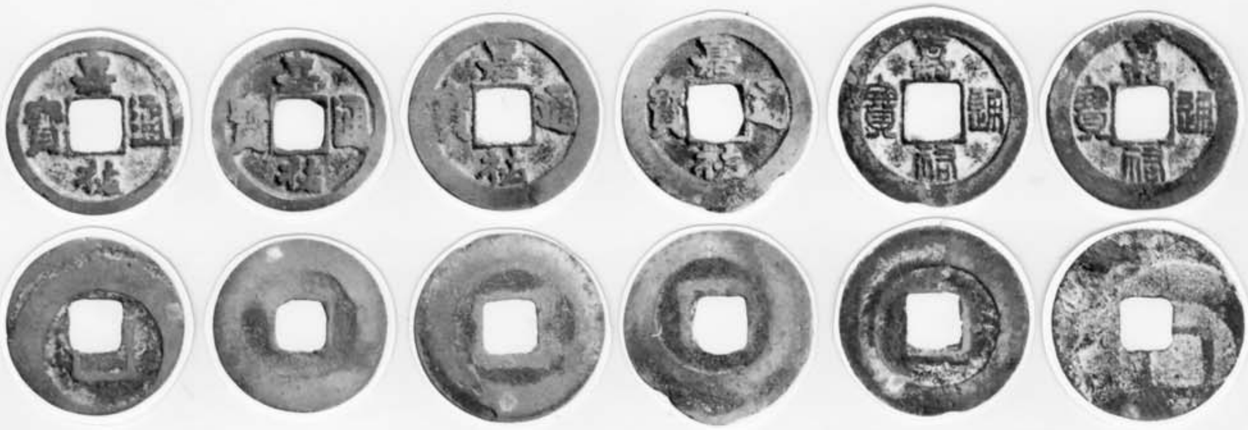

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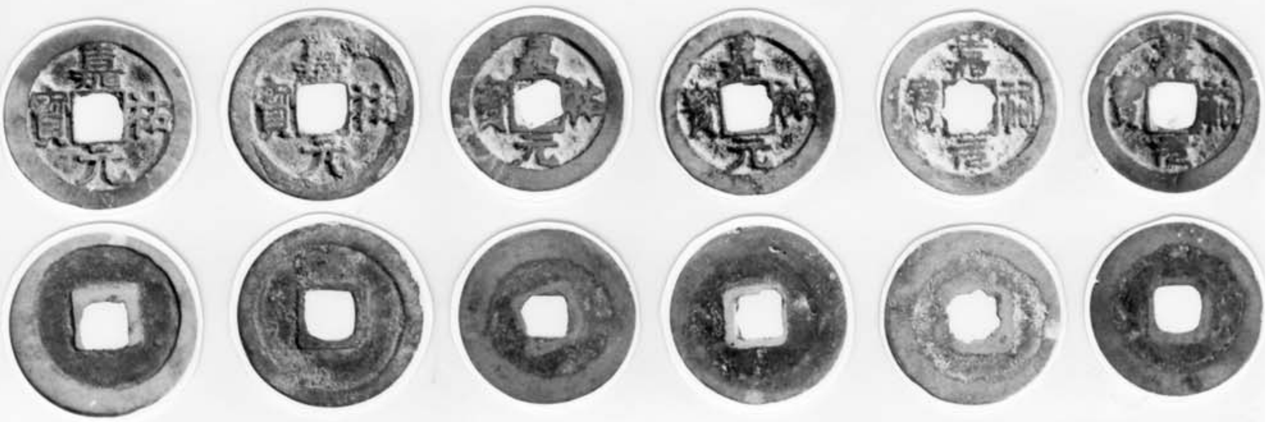

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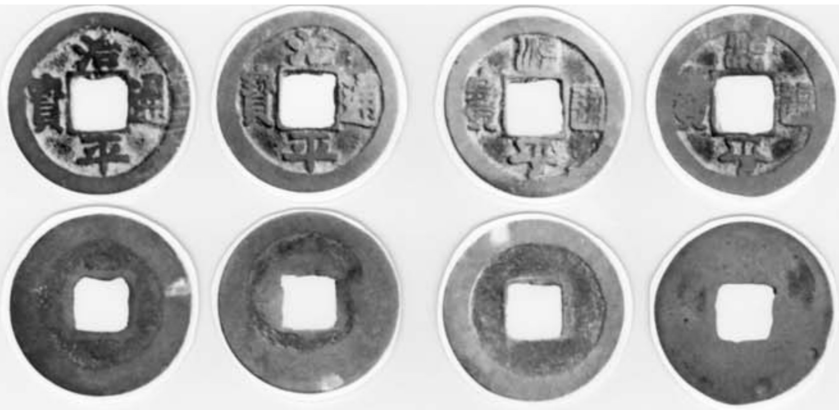

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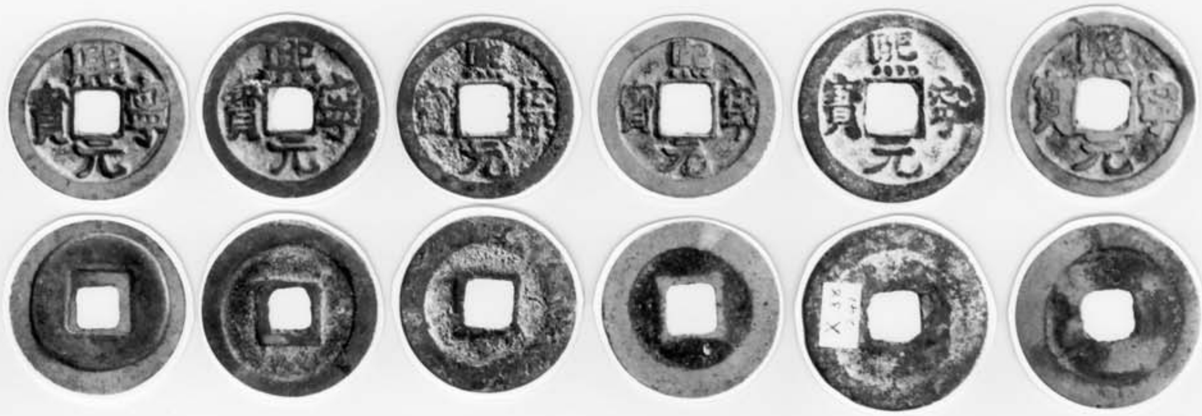

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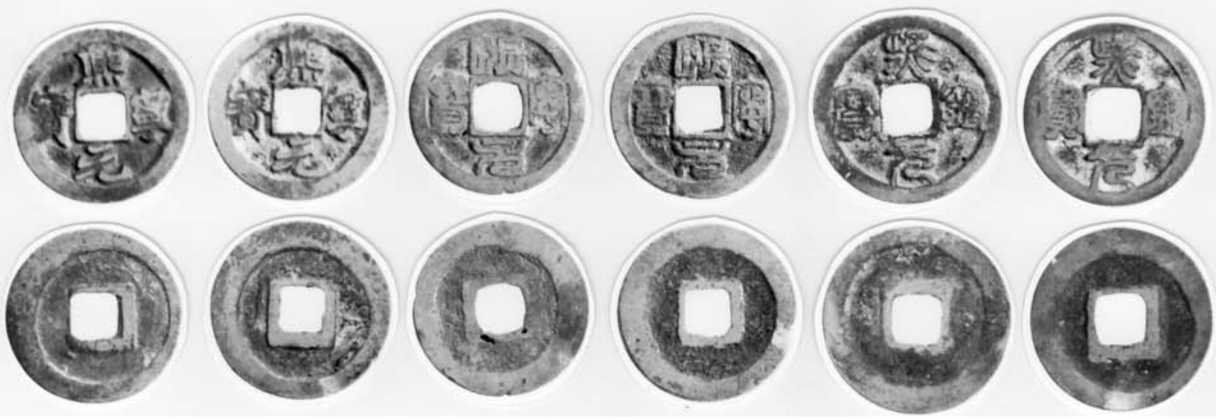

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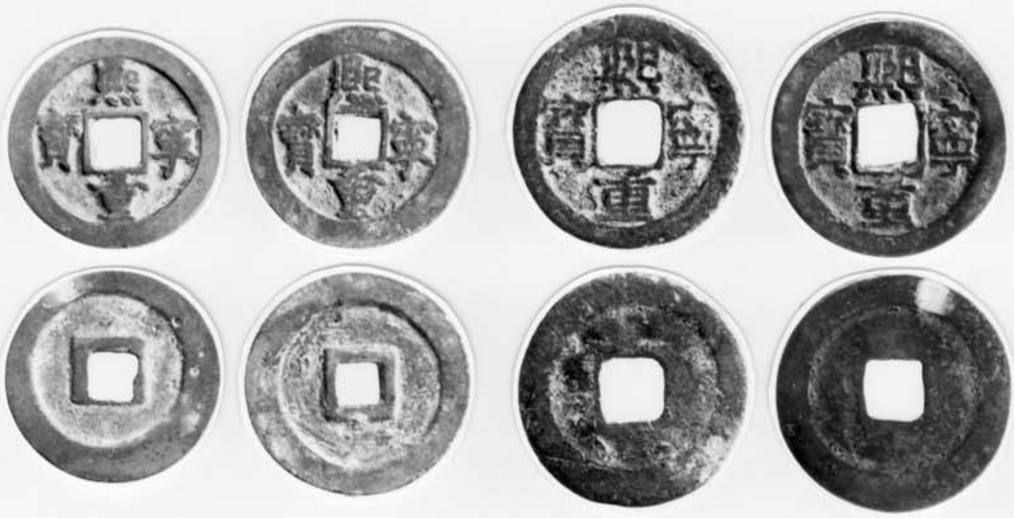

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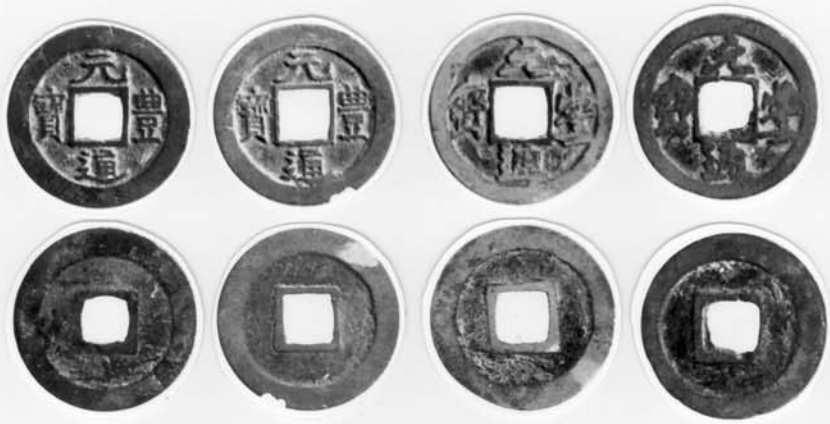

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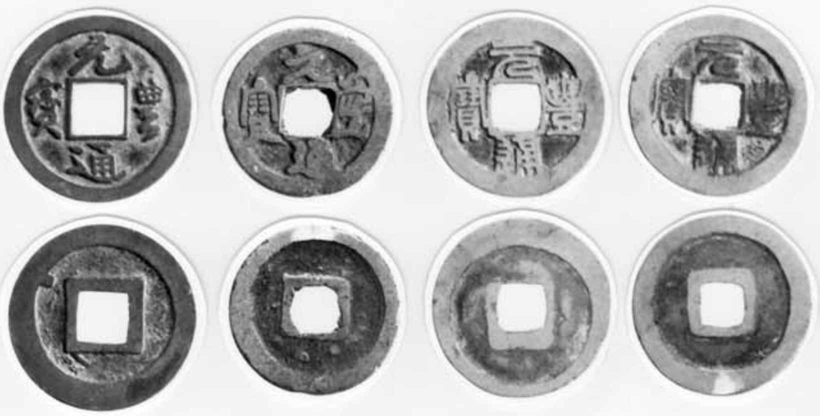

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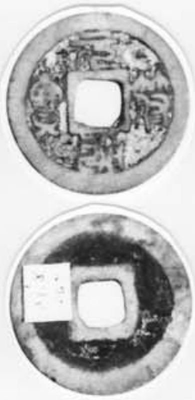
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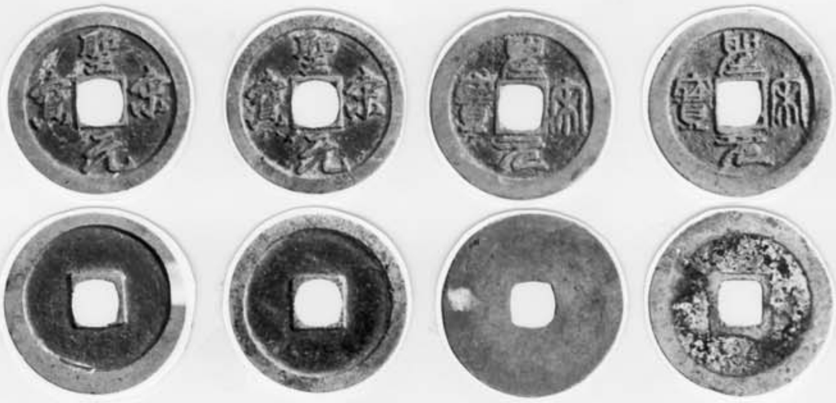

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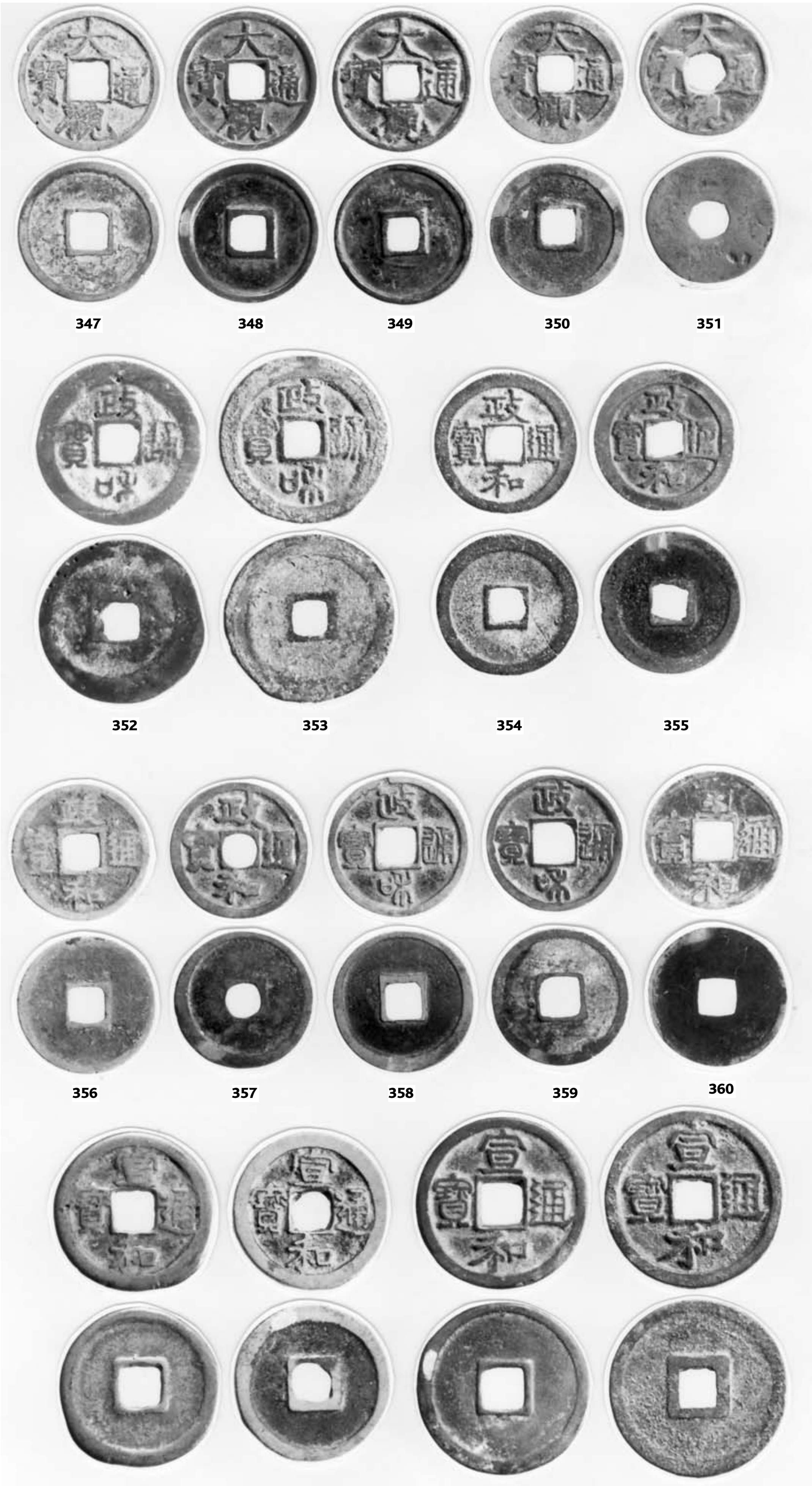

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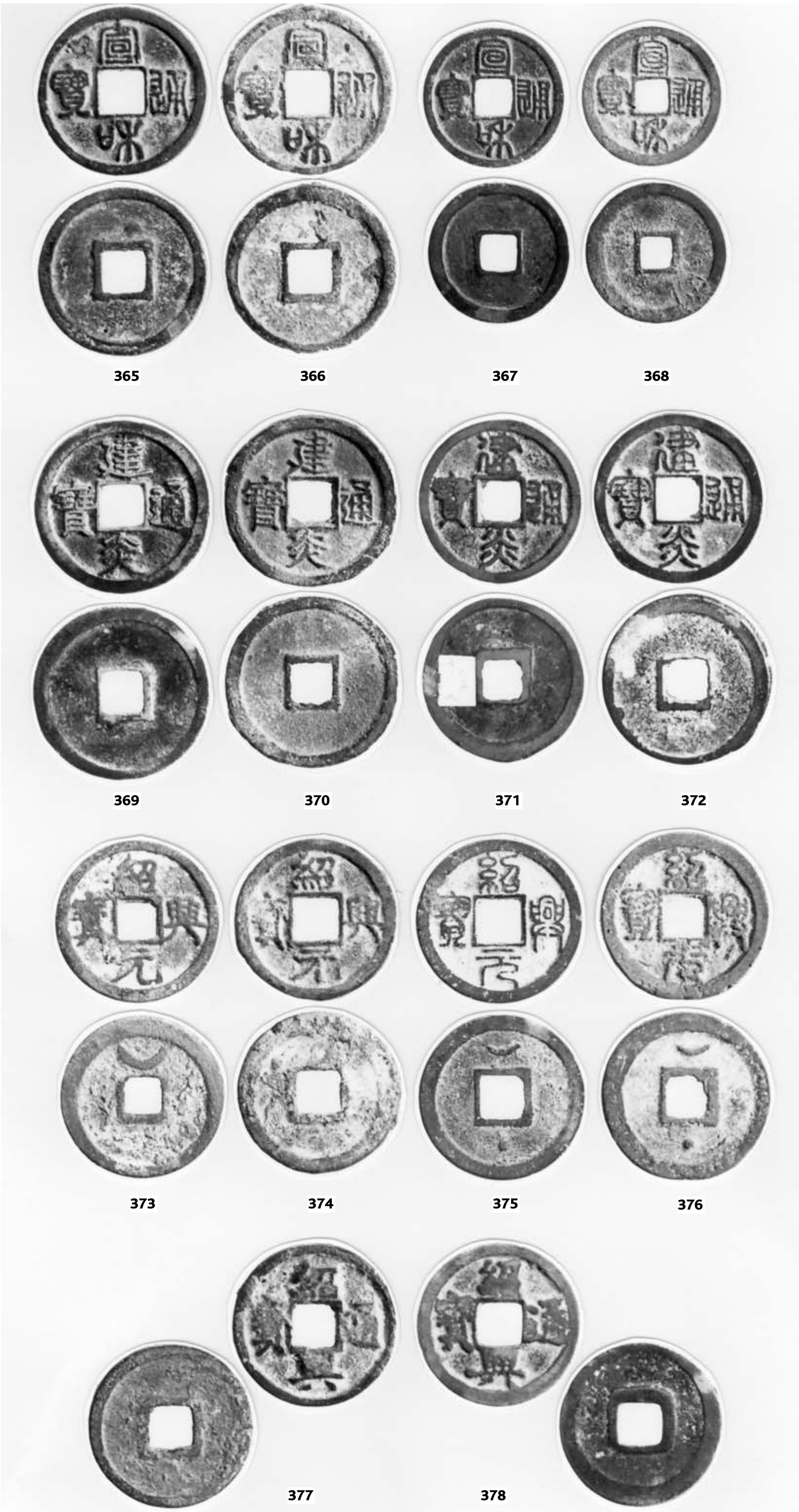

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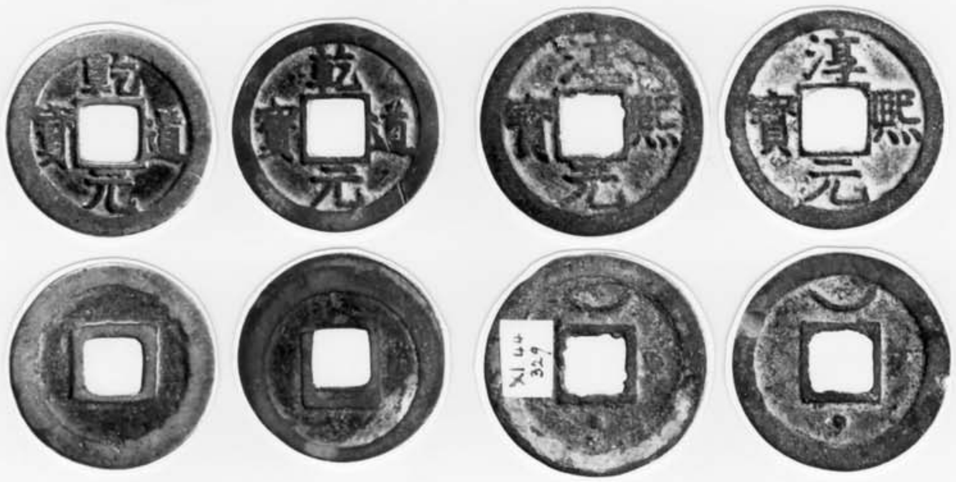

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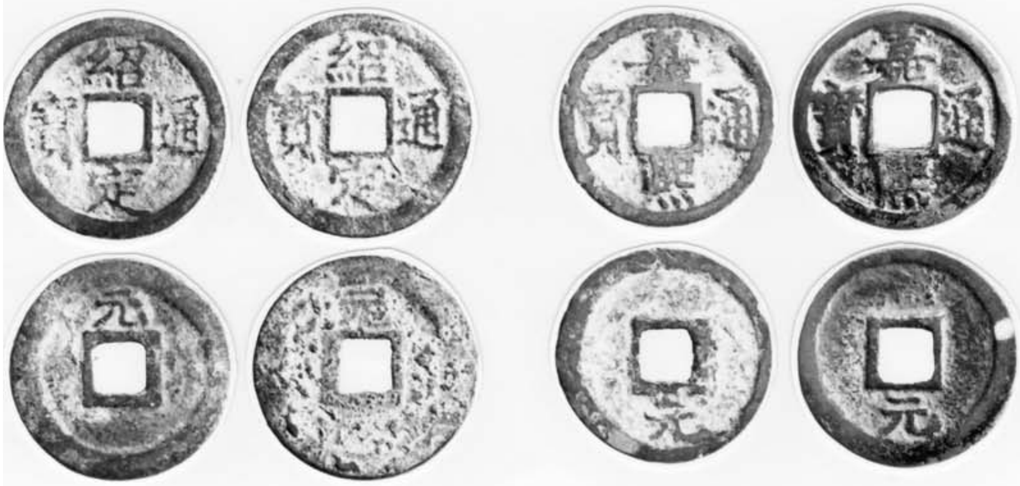

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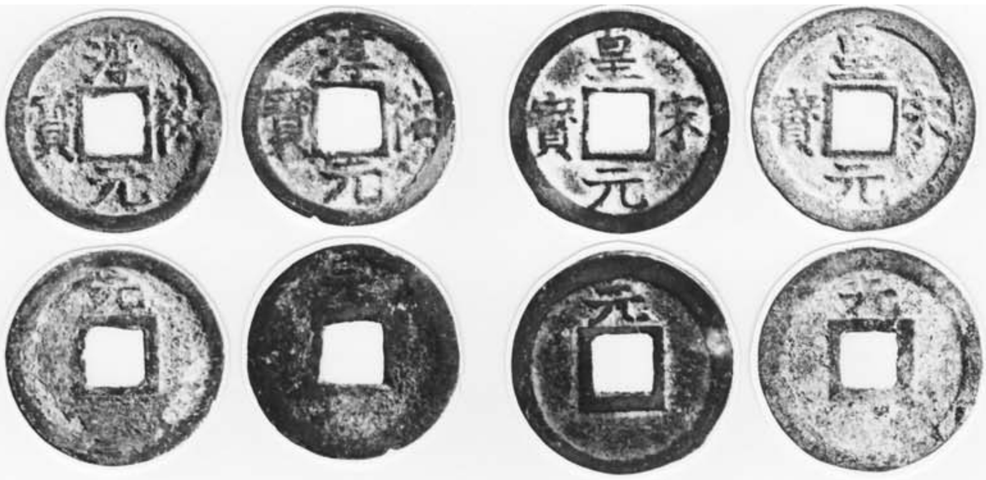

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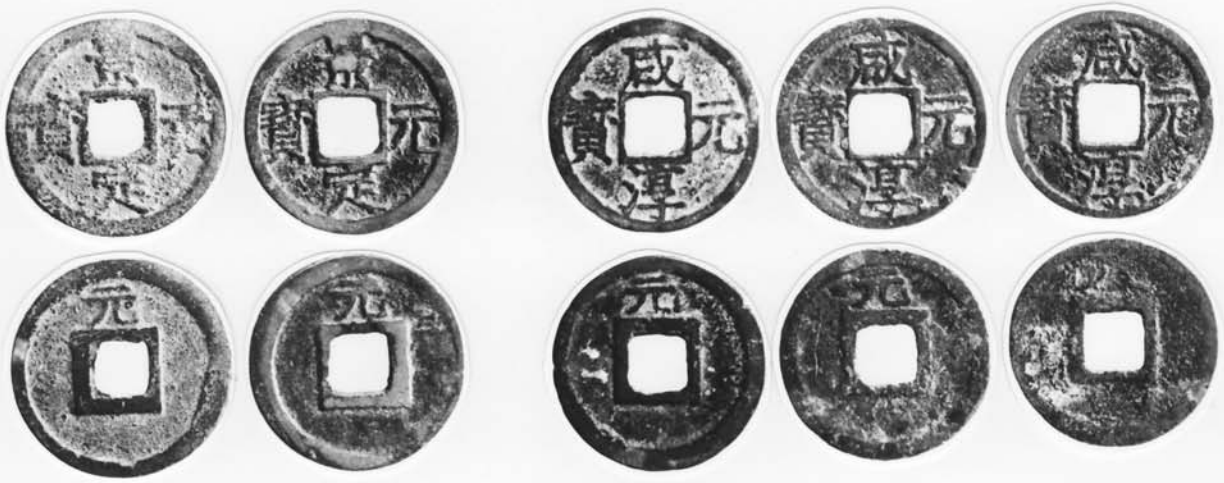

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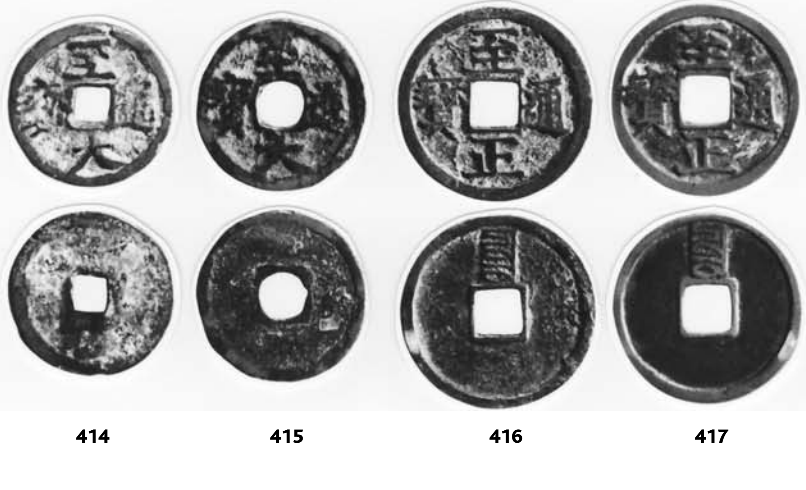

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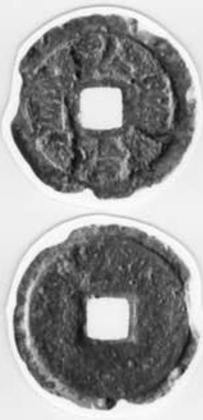
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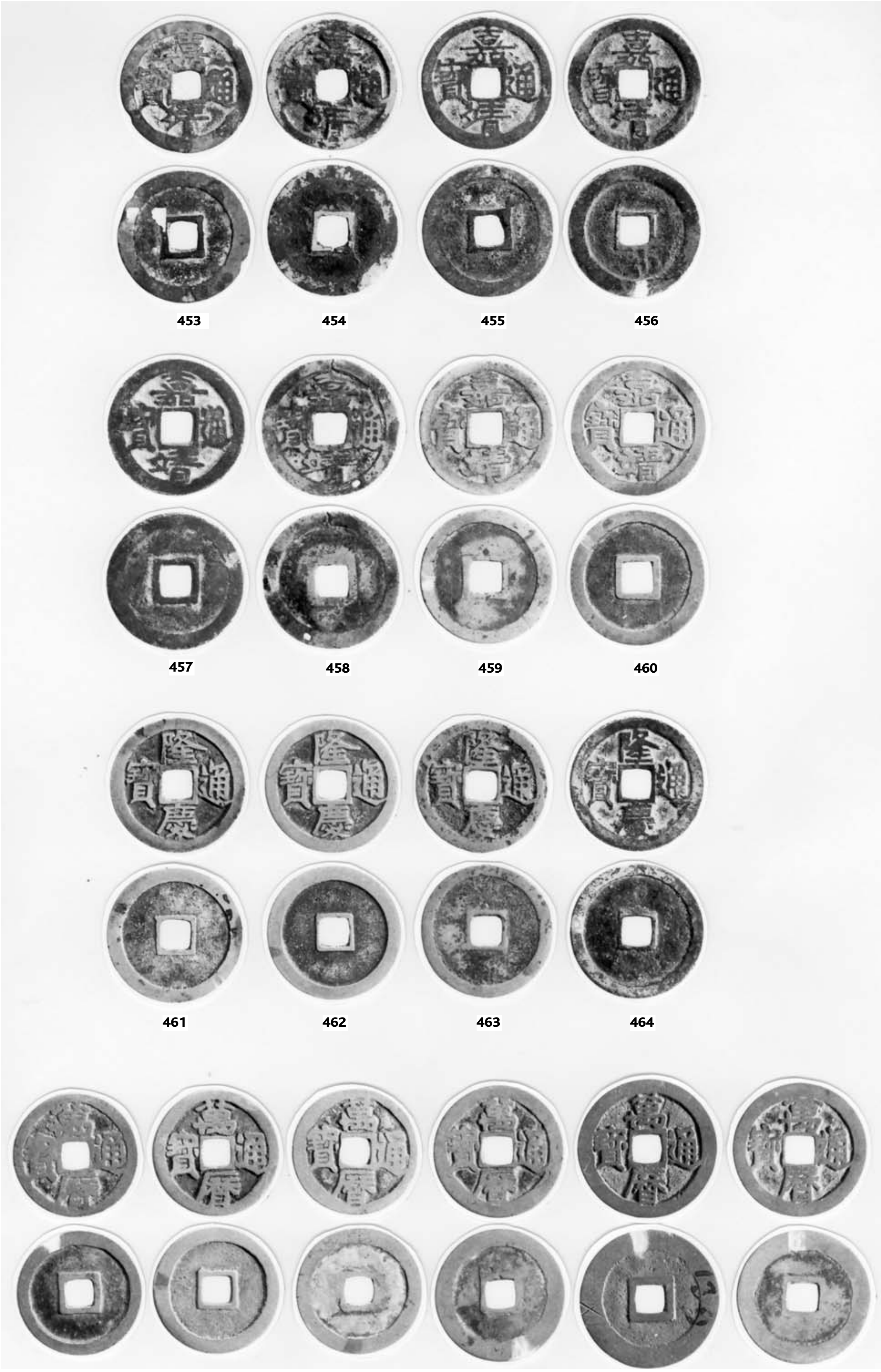

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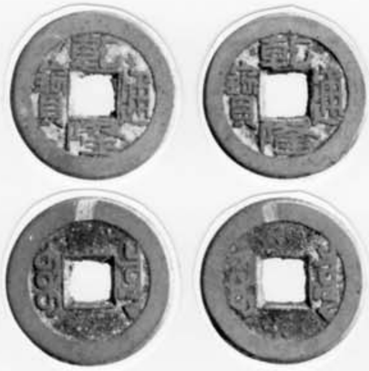

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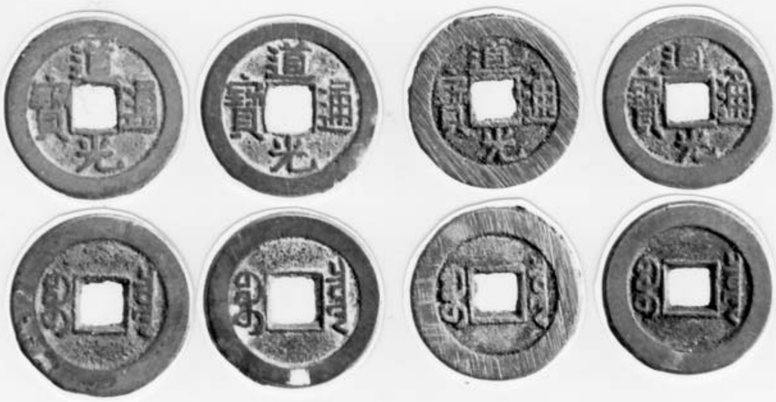

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The Chinese Cash: Composition and Production

Michael Cowell, Joe Cribb, Sheridan Bowman
and Yvonne Shashoua

Introduction

In this paper we summarise the results of an analytical survey of the Chinese cash copper alloy coinage from the earliest issues of the Han period in the 3rd century BC to the end of the Qing dynasty in the early 20th century. Details of the analytical techniques used can be found elsewhere,[1] the analytical data for the later coins is listed in **Table 2**.

The survey was instigated primarily to provide a dated series of analyses of typical Chinese copper-based metalwork. This has revealed new information about the developments of alloying in China for coinage manufacture which can be compared with methods used for other types of artefact. The contemporary records of cash production, which often specify the quality and quantities of the various metals used in the alloy and individual mint practices, may also be correlated with the established composition of the coins. The most important aspect in this respect is the first use of brass for the coinage and the information which analysis provides about the technology of its manufacture.

Manufacturing technique and alloys

Although economics would no doubt have been an important factor in the type of alloys used for the manufacture of the cash, as in all aspects of currency production, due account had also to be given to the methods by which the coinage was produced. Throughout the whole of the period surveyed the cash was manufactured entirely by casting. Contemporary accounts indicate that there were periodic modifications to the process, but these were primarily concerned with the materials or the manner with which the moulds were made.

The most complete description of the manufacturing procedure specifically relates to mid-17th-century practice,[2] when vertical sand (loess) moulds were used to cast batches of coin on a tree-like network (**Pl. 1.1 see cover**) weighing up to 6kg, but the general principles of the operation had changed little for over a millenium. After casting the coins were separated from the tree structure linking them together. They were then carefully cleaned and abraded to remove sprue, and finally strung together in thousands.

There are advantages in producing coins by casting rather than striking. The process is labour intensive but involves relatively simple technology, especially when compared with machine methods, and requires less skilled personnel as might be employed in most foundry workshops. A major disadvantage is that forgery is easy and difficult to detect since a single authentic coin can be used to produce any number of copies using the same process by which the original was made. Very detailed designs cannot be reproduced consistently and individual accurate weight control could also be difficult to achieve. The technique was most suited, therefore, to the mass production of a low value base-metal denomination, such as the cash, where the profit margin was small.

For casting cash, alloys had to be used which were suitable for this method of production. These would not necessarily be appropriate for the manufacture of coinage by striking, particularly if sheet metal was required for the blanks. Essentially two types of alloy were used for cash manufacture over the period surveyed: tin bronze up to the early 16th century and then brass until the early 19th century. For virtually the whole of this period, however, irrespective of whether bronze or brass was used, the alloys are leaded. The chronological variation in the lead content is illustrated in **Fig.1**. The lead content is highest in the bronze coins and typically ranges from 10 to 20%, peaking at around 30% for coins issued during the 12th and 13th centuries. In the brass coins the lead content is lower and mostly in the range 2 to 8%, averaging about 5%. The use of leaded alloys was partly influenced by the cost and availability of metals, but their technical suitability must also have been a major consideration.

The addition of lead to bronze or brass has two important effects: it slightly lowers the freezing point of the alloy (by about 100°C with 20% lead added to bronze) and markedly increases the fluidity of the molten metal.[3] Both of these features are desirable in the manufacture of small, detailed items by casting. The increase in fluidity is most marked up to about 3% lead after which there is a slow but further steady improvement. This is just below the concentration in the later brass issues where the lead has probably been added solely for technical rather than economic reasons. By contrast, during the 12th and 13th centuries when the lead content was highest it was almost certainly added primarily to reduce costs.

Developments in brass production

The major change in the coinage alloy from bronze to brass occurred during the early part of the 16th century, specifically during the later Hongzhi period, 1503–05 (**Pl. I.3–5**). This changeover was almost certainly prompted by economics. As zinc became a cheaper metal than lead it was profitable to substitute zinc for some of the lead and most of the tin without detriment to the properties of the alloy. In fact, there would have been some improvement since zinc is a better de-oxidant than tin and the quality of the castings would have been improved.

For some time the alloy used was not a 'pure' brass but one more accurately described as a quaternary alloy containing substantial amounts of tin and lead in addition to zinc and, of course, copper (**Fig. 2**). The lead content was soon reduced and stabilised but the tin content had virtually disappeared by the 17th century. It is of particular interest to establish when the Chinese first used brass for their coinage and, most importantly, to determine how that brass was manufactured.

Zinc is not an easy metal to isolate in the pure state because it is very readily oxidised and has a low boiling point (913°C).

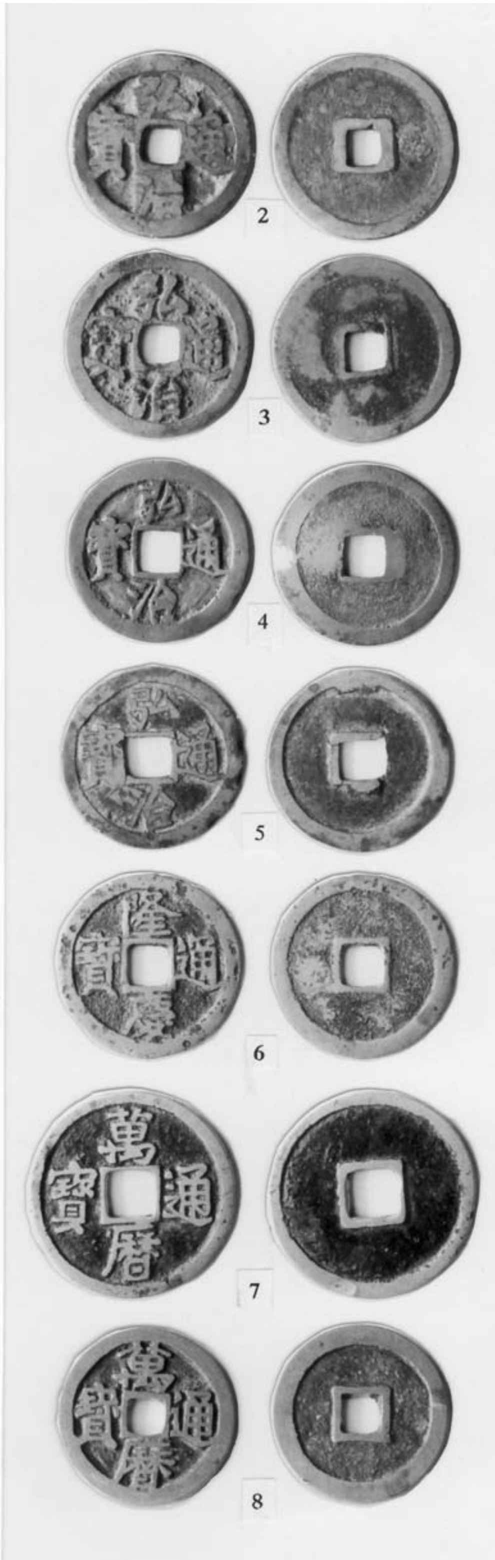

Plate 1.1 See cover Chinese 'money tree', brass 10 cash coins still attached to casting sprue. This example was made at the Board of Revenue Mint, Beijing, *c.*1905.
Plate 1.2–3 Bronze versions of Hongzhi tongbao coins of the Ming dynasty, issued in 1503 (16th year of the Hongzhi reign period). Coin nos 440 and 436.
Plate 1.4–5 Brass versions of Hongzhi tongbao coins of the Ming dynasty, issued in 1505 (18th year of the Hongzhi reign period). Note the different calligraphic style of the inscriptions, which are written with thinner strokes than those on the bronze coins (2–3). Coin nos 450 and 451.
Plate 1.6 Lacquered brass version of Longqing tongbao coins of the Ming dynasty, issued 1570 (4th year of the Longqing reign period). Coin no. 463.
Plate 1.7–8 Lacquered brass versions of Wanli tongbao coins of the Ming dynasty, issued 1537–82 (Wanli reign period). Coin nos 480 and 471.

Conventional smelting will readily produce the free metal but this immediately vapourises, re-oxidises and is lost with the flue gases. To extract the pure metal in any quantity requires a complex reduction, distillation, and condensation process which may have been first perfected in India during the 14th century AD or perhaps a little earlier.[4] Brass can, however, be manufactured directly by the cementation process, used extensively by the Romans, in which zinc metal is generated, by reduction, from an ore mixed with reducing agents in close contact with copper metal in a closed vessel. The zinc vapour, formed *in situ*, is absorbed by the copper to produce brass. This process has been known since the 3rd century BC but limits the brass composition which can be made to those containing not more than about 28% zinc.[5] On the other hand, with metallic zinc available there is no upper limit to the composition of brass which can be manufactured.

The point at issue here is whether the Chinese were using brass for their coinage which had been made by the older cementation method or from metallic zinc and copper, that is by speltering. The primary source of information on 17th-century manufacture, the *Tian gong kai wu* [*T'ien-kung k'ai-wu*] clearly refers to the use of metallic zinc by specifying the quantities of the individual metals.[6] The current analyses show that the brass coinage can be traced back over 100 years before the date of that publication and there is strong evidence that all these brass issues, from their inception during the Hongzhi period in the early 16th century, were made by speltering rather than cementation.

The evidence centres on the large amounts of lead and, particularly, tin in the early brasses. Most of the early 16th-century brass coins contain less than the 28% zinc limit achievable by cementation manufacture and all could, in theory, have been made using that process. However, the large amounts of tin and lead also present are unlikely to have been introduced into the alloy as pure metals. In fact there would have been little point in continuing to add the much more expensive tin since, as noted above, zinc is equally effective metallurgically. It is much more likely that the tin and lead were introduced, along with copper, by the re-cycling of scrap leaded bronze coinage (or other cast metalwork) which seems to have been normal practice at the mint. The results suggest that for the earliest issues up to 50% of the metal input could have been in the form of scrap. On this assumption, if cementation brass had been used the dilution with scrap would have resulted in a zinc content below that actually found in the coins.

There are two items of near contemporary information which substantiate the production of brass for coinage at this time and, incidentally, the use of metallic zinc for this purpose. The geographer Gu Ziyu [Ku Tsu-yu], writing in 1667, reports that brass coins were used from 1520,[7] and in the *Ming shi* [*Ming Shih*] it is noted that a proportion of a different metal, described as 'good' or 'superior tin' was *added* to some of the issues in the Hongzhi period, 1503–05.[8] This may be referring to zinc because the quantities involved are close to those actually found in the coins. The minor difference in the dates at which brass was first reportedly used is reconciled by the fact that only a minority of the Hongzhi coins are described as brass (actually 10% of the issues examined so far prove to be of that alloy) whereas after this period (i.e. later than 1520) *all* the central mint coins are brass.

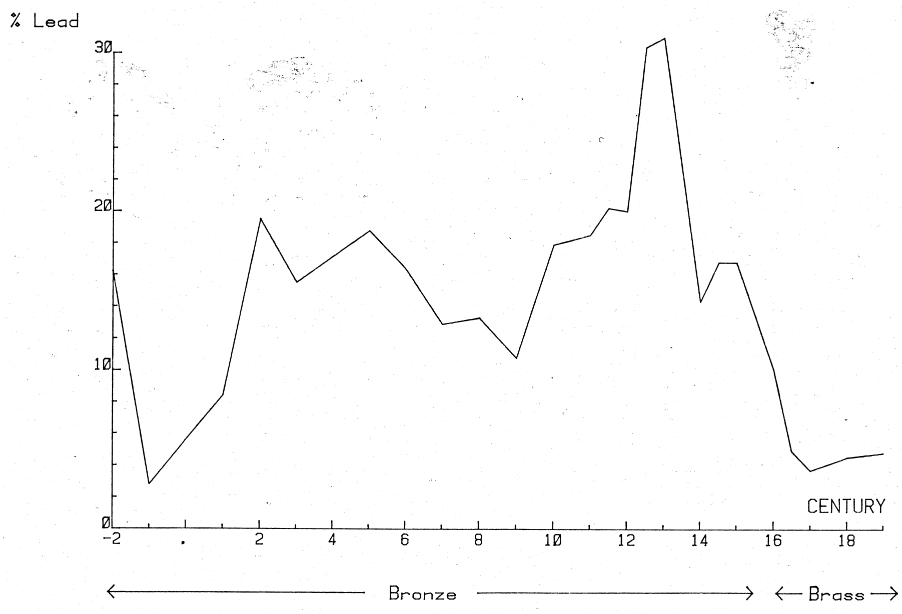

Figure 1 Average lead content

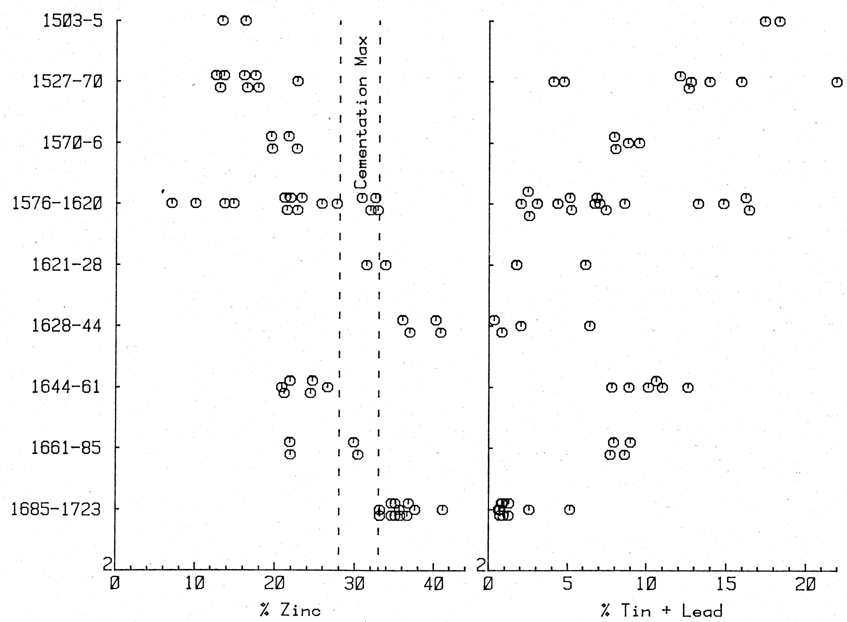

Figure 2 Alloy composition of the early brass issues

The signficance of this early availability of metallic zinc is that it substantially predates its introduction to Europe.[9] The analyses unfortunately cannot precisely determine whether the 16th-century zinc was made in China, as it most certainly was by the early 17th century, or if it was imported, possibly from India. However, there is some indication of either a change in the method of zinc manufacture or its source during the 17th century from the concentration of the metal cadmium in the brass coins. In coins issued before about 1620 cadmium is usually not detected and never exceeds 0.002% (20 ppm). After this date the cadmium concentration is often much higher (although it never exceeds trace amounts) with some later coins containing over 0.01% (100 ppm) of the metal.

There are several possible explanations for this increased cadmium content. Cadmium minerals are commonly associated with zinc ores and would be expected to be extracted with that metal. Therefore the increase may simply be the result of exploiting different, cadmium-rich, zinc ore sources. Alternatively, the use of a different method of ore treatment or smelting may have resulted in the retention of cadmium in the zinc metal whereas previously it was lost. There are significant differences between the Indian and Chinese methods of zinc manufacture. In the Chinese method, as illustrated in the *Tian gong kai wu*, the metallic zinc is retained within the sealed vessel containing the reduction mixture but in the Indian process the zinc is distilled off into a separate, cooled, receiver.[10] Cadmium is more volatile than zinc (b.pt.765°C as opposed to 913°C) and would therefore be more readily lost during a distillation process like that used in India but retained in the sealed container used in China. Nevertheless, ore processing could also be an important factor. For example, any pretreatment of ores by roasting would encourage the preferential loss of cadmium which might otherwise be retained in the metal. A changeover from sulphide (sphalerite) ores, which required roasting to the oxide prior to smelting, to carbonate (smithsonite) ores might therefore influence the cadmium content of the end product.

Mint standards

The dynastic histories often record the quantities of the various metals used in the casting of coins. For the Ming and Qing dynasties the normal quantities of metal used were 6 or 7 parts of copper and 3 or 4 parts of zinc.[11] However, coins containing the most zinc were the least regarded and first class cash contained only 1 part zinc to 9 parts copper whereas forgeries were said to consist of equal amounts of the two metals. Nevertheless, due to acute shortages of copper, there was an official decision in 1683 to increase the proportion of the cheaper zinc in the coinage alloy from 30 to 40%.[12]

The composition of coins issued up to 1723 (**Fig. 2**) shows that very few contain 40% or more of zinc, the majority falling between 20 and 38%. Histograms show peaks at around 22% and 35% zinc. There would, therefore, appear to be little correspondence with the quoted composition of the coinage. However, a factor which must be taken into account is the volatility of zinc both during the primary manufacture of brass by speltering or the re-melting of scrap brass. According to the *Tian gong kai wu*, for the formulation of brass, zinc was added to molten copper (which would be at a temperature above the boiling point of zinc) and this could result in the loss of a quarter of the zinc added. If this loss was not compensated for by adding more than the stipulated amount then the final alloy would contain substantially less zinc than was intended. Indeed, it is probable that the quoted proportions of metal refer to the actual amounts to be *used* by the mint (i.e. added to the copper) and not the final composition to be aimed at.

Taking these losses into account, we can compare the average measured composition of coins issued just before and just after the alloy change in 1683 with their expected compositions (**Table 1**).

Table 1 Analysed zinc contents compared with documentary references

Date	% Zinc (mean)	Quoted zinc formulation	
		Amount added	After 25% loss
1644-85	24.3	30	24
1685-1723	36.3	40	33

The actual composition of these coins is thus in reasonable accordance with the documented intentions and practices of the mint.

Surface treatment

An extraordinary mint practice initiated in the Ming dynasty, which was apparently prompted by the purity of the raw materials, and also by the quantity of zinc in the alloy, was the application of lacquer to the coin surface. The *Tian gong kai wu* notes that there were two types of yellow (brass) cash in the early 17th century: gold-back cash using four times refined copper and fire-lacquer cash using only two times refined copper. The latter coins were apparently coated on both sides with black lacquer over a fire to protect the less refined alloy from corrosion. It is also implied that less zinc was added to the alloy used for the fire-lacquer cash. This clearly time-consuming and probably expensive operation was presumably one of the last steps in what was already a labour-intensive process of coin manufacture.

The lacquering still appears to survive on many coins of the 16th to the 18th centuries as either a black sheen on the lowest parts of the field or a black waxy material infilling the recesses between the lettering (**Pl. 1.7–8**). It never seems to be present on the raised parts of the design which in any case would have been rubbed clean once the coins left the mint. A number of coins dating from 1527 to about 1736, which visually show strong evidence of lacquering, have been examined to establish the nature of this coating. Fourier Transform Infrared Spectroscopy (FTIR) was used to analyse small samples taken from surfaces of the coins.[13]

All the samples, except one from a coin issued in the period 1646–53, produced spectra comparable with urushiol,[14] which is the characteristic constituent of Chinese or Japanese lacquer. This is derived from the sap of a tree, *rhus vernicifera*, and was widely used in the East as a decorative material on organic, ceramic and metallic artefacts. One coin had been coated with shellac which is of insect origin. The application of lacquer appears to have continued, therefore, well into the 18th century.

The original purpose of the lacquer, to protect issues made from less refined metal, implies that there should be a difference in the composition of coins with and without lacquer. An examination of elements in the alloy which would be reduced in concentration by prolonged refining (e.g. antimony and arsenic) indicates that there are slightly higher amounts in the lacquered coins (antimony plus arsenic averages 0.35%) compared to those with no lacquer apparent (0.29%). The differences are hardly significant and may be less clear cut because, whereas lacquered coins can easily be identified, it is of course impossible to be certain whether those without a coating now were never lacquered or have simply lost the coating through cleaning and corrosion.

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Notes

1 S.G.E. Bowman, M.R. Cowell and J. Cribb, 'Two thousand years of coinage in China: an analytical survey' *Historical Metallurgy* 23 (1989), 25–30.
2 Song Yingxing [Sung Ying-Hsing], *Tian gong kai wu* (1637). See translations by E-Tu Zen Sun and Shion-Chuan Sun, *Chinese Technology in the 17th Century* (Pennsylvania, 1966), 165–69, which refers specifically to coin manufacture, and also to that by W. Burger, *Ch'ing Cash until 1735* (Taiwan, 1976), especially 22–24.
3 J. Young, 'The addition of lead to alloys in the Late Bronze Age' (Institute of Archaeology, London, BSc project report, undated and unpublished).
4 The Indian process, as used at Zawar, is described by P.T. Craddock, L.K. Gurjar and K.T.M. Hegde, 'Zinc production in mediaeval India', *World Archaeology* 15 (1983), 211–17. The traditional Chinese process, with little modification, was still being used relatively recently; the process has been described by Xu Li, *Ziran kexue shi yanjiu (Studies in the History of the Natural Sciences)* 5 (1986), 361–69, now translated by J.O. Petersen, 'Traditional zinc smelting in the Guima district of Hezhang County', in *2000 Years of Zinc Smelting* (British Museum Occasional Paper 50, 1990), 103–22.
5 A. Burnett, P.T. Craddock and K. Preston, 'New light on the origins of

aurichalcum', in *Proceedings of the 9th International Congress on Numismatics* (Berne, 1979), 263–68; P.T. Craddock, A. Burnett and K. Preston, 'Hellenistic copper-based coinage and the origins of brass', in *Scientific Studies in Numismatics* (British Museum Occasional Paper 18, 1980), 53–64. It is possible to produce cementation brass with a higher zinc content of 33–34% if the copper is in granular form, i.e. of large surface area, produced by pouring the molten metal through a mesh and into water. This modified process was patented in England in the early 18th century but similar methods were probably practiced earlier than this in Europe in general. See, for example, J. Day, *Bristol Brass: History of an Industry* (Newton Abbott, 1973); M.B. Mitchiner, C. Mortimer and A.M. Pollard, 'The alloys of continental copper-base jetons (Nuremberg and mediaeval France excepted)', *Numismatic Chronicle* 148 (1988), 117–28.

6 E-Tu Zen Sun and Shion-Chuan Sun, *Chinese Technology*, 165.

7 Gu Ziyu [Ku Tsu-yu], *Tushi yu ji yao* [*Tu shih yu chi yao*] (1667). See J. Needham, *Science and Civilisation in China,* V:2 (Cambridge, 1974), 231.

8 O.Y. Tsai, *Zhongguo guquan jianghua* (Taipei, 1973); F. Thierry, 'Le monnayage de l'empereur Xiao Zong des Ming (1487–1505): deux variétés inédites', *Bulletin de la Société Française de Numismatique* (Jan, 1987), 139–41.

9 Zinc had been exported to Europe from the East since the early 17th century, see Needham, *Science and Civilisation*, 212.

10 See note 4.

11 E-Tu Zen Sun and Shion-Chuan Sun, *Chinese Technology*, 165.

12 Burger, *Ch'ing Cash*, 67. At this time there was also an influx of foreign copper, chiefly from Japan. This seems to be reflected in a composition change since coins of this period (1662–1722, middle and late issues) have lower concentrations of antimony, nickel, arsenic and cobalt, all elements which may be related to the copper source.

13 We are grateful to the staff of the Conservation Department of the Victoria and Albert Museum for allowing us to use their FTIR instrument.

14 J. Kumanotani, A. Achiwa, R. Oshuna and K. Adachi, 'Japanese lacquer as a durable material', *Cultural Property and Analytical Chemistry* (1979), 51–62.

Table 2 Analyses of Chinese cash issues after AD 1400

No.	Table no.	Date	Period	%Cu	%Zn	%Sn	%Pb	%Fe	%Sb	%As	%Ni	%Ag	%Co	%Cd	%Mn	%Bi
26	426	1408	-	73	.10	8.5	18.0	.20	<.05	<.20	<.05	<.03	-	-	-	-
25	427	1408	-	72	.10	8.0	19.0	.70	<.05	<.20	<.05	<.03	-	-	-	-
535	430	1433	-	70	.01	8.2	18.5	.18	.21	.40	.04	.08	.009	-	<.0007	.10
533	432	1433	-	72	.02	8.6	13.5	.21	.23	.40	.04	.09	.010	-	.0017	.10
532	433	1433	-	67	.04	7.5	22.9	.17	.26	.50	.04	.10	.007	-	.0017	.11
24	428	1433	-	78	.10	7.6	14.0	.90	<.05	<.20	<.05	<.03	-	-	-	-
23	429	1433	-	73	.30	9.3	16.0	1.10	<.05	<.20	<.05	<.03	-	-	-	-
534	431	1433	-	77	1.50	8.0	14.0	.31	.14	.10	<.05	.08	-	-	-	-
549	452	1503-5	-	77	<.10	5.0	17.2	.03	.46	.50	<.05	.07	-	-	-	-
543	445	1503-5	-	66	<.01	6.7	23.0	.09	.08	.20	.04	.34	.013	-	.0010	.09
541	443	1503-5	-	71	<.01	8.5	16.2	.06	.13	.10	.08	.07	.005	-	.0005	.11
538	440	1503-5	-	71	<.01	10.6	14.8	.01	.08	1.00	.02	.03	.003	-	<.0006	.04
427	436	1503-5	-	-	.06	10.1	11.7	.21	.17	.28	.04	.10	.005	<.0008	.0012	.08
547	449	1503-5	-	72	.10	9.3	17.8	.11	.27	<.10	.06	.09	-	-	-	-
539	441	1503-5	-	76	.22	3.7	15.7	.05	.10	.10	.03	.18	.006	-	<.0007	.05
21	435	1503-5	-	87	.41	8.5	3.7	.13	<.05	<.20	.12	<.03	-	-	-	-
426	437	1503-5	-	79	.45	7.6	12.4	.05	<.05	<.20	.05	.10	-	-	-	-
537	439	1503-5	-	82	.70	16.0	.6	.08	<.02	-	<.05	.05	-	-	-	-
536	438	1503-5	-	78	.96	7.7	11.6	.03	.07	.10	.03	.03	.004	-	<.0006	.04
546	448	1503-5	-	78	1.00	10.8	4.9	.39	.05	.04	.05	.06	.005	-	.0027	.02
544	446	1503-5	-	77	1.20	10.7	6.8	.14	.07	.20	.05	.05	.004	-	.0007	.03
22	434	1503-5	-	-	1.23	9.8	2.8	.54	.06	.29	.07	.07	.007	<.0012	.0029	<.02
545	447	1503-5	-	77	1.30	10.9	4.1	.17	.03	.08	.05	.07	<.008	-	.0016	.09
542	444	1503-5	-	81	1.60	10.0	7.0	.14	.02	.10	<.05	.03	-	-	-	-
540	442	1503-5	-	85	1.70	10.0	2.8	.23	<.02	.10	.07	.02	-	-	-	-
548	450	1503-5	-	69	13.3	7.8	9.6	.04	<.02	<.10	<.05	<.03	-	-	-	-
550	451	1503-5	-	66	16.2	7.4	10.9	<.20	-	-	-	-	-	-	-	-
430	458	1527-70	-	-	12.5	3.2	.8	.08	.04	.10	<.01	.08	.007	<.0012	<.0007	<.02
429	456	1527-70	-	69	13.0	7.4	8.5	2.00	<.05	<.20	<.05	<.03	-	-	-	-
431	457	1527-70	-	-	13.5	4.0	.7	.52	.03	.08	<.01	.05	<.006	<.0010	.0040	<.02
433	459	1527-70	-	70	16.0	5.5	7.2	.86	.36	.27	.08	.04	-	-	-	-
428	455	1527-70	-	60	16.4	7.5	14.4	.92	.39	.24	.12	<.03	-	-	-	-
432	460	1527-70	-	70	17.4	5.5	6.5	.29	.23	.29	.06	.03	-	-	-	-
20	454	1527-70	-	-	17.8	7.4	5.2	.36	.05	.26	.04	.02	<.010	<.0016	<.0010	.05
19	453	1527-70	-	63	22.7	6.9	7.0	.06	.12	.00	.01	.04	<.006	<.0011	<.0006	.04
435	463	1570-76	-	68	19.4	6.3	3.2	3.40	<.05	<.20	<.05	<.03	-	-	-	-
18	461	1570-76	-	-	19.5	5.8	3.0	.23	.04	.03	<.01	.05	<.005	.0009	<.0005	<.02
434	464	1570-76	-	59	21.6	5.2	2.7	11.1	<.05	<.20	<.05	<.03	-	-	-	-
17	462	1570-76	-	-	22.6	4.1	2.9	.33	.04	.07	<.01	.04	<.005	.0012	.0014	<.02
439	478	1576-1621	-	76	6.94	5.7	10.5	.47	.11	<.20	.13	.05	-	-	-	-
440	479	1576-1621	-	-	9.95	8.1	8.3	.32	.20	.49	.06	.12	.008	<.0014	<.0008	<.03
437	476	1576-1621	-	79	13.6	3.7	3.0	.79	.08	<.20	<.05	.03	-	-	-	-
438	477	1576-1621	-	70	13.7	2.0	11.2	2.50	.11	<.20	<.05	<.03				
441	480	1576-1621	-	-	14.7	4.2	10.6	.33	.07	.16	.05	.04	.007	<.0011	<.0007	<.02
531	470	1576-1621	-	76	21.1	.4	2.0	.19	<.05	<.20	<.05	<.03	-	-	-	-
15	472	1576-1621	-	-	21.4	1.4	1.1	1.25	.05	.09	.04	.02	.014	<.0008	<.0005	<.02
527	466	1576-1621	-	72	21.8	2.9	2.2	1.10	<.05	<.20	<.05	<.03	-	-	-	-
16	471	1576-1621	-	-	22.7	4.0	4.6	.44	.10	.40	.03	.04	.004	<.0007	.0011	.09
436	475	1576-1621	-	69	23.2	4.3	2.5	.73	<.05	<.20	<.05	.03	-	-	-	-
528	467	1576-1621	-	67	25.7	1.3	6.1	.38	<.05	<.20	<.05	<.03	-	-	-	-
530	469	1576-1621	-	70	27.6	.1	1.9	.53	.07	.35	<.05	<.03	-	-	-	-

Table 2 (cont.) Analyses of Chinese cash issues after AD 1400

No.	Table no.	Date	Period	%Cu	%Zn	%Sn	%Pb	%Fe	%Sb	%As	%Ni	%Ag	%Co	%Cd	%Mn	%Bi
529	468	1576-1621	-	62	30.8	1.7	5.3	.42	.06	<.20	<.05	<.03	-	-	-	-
14	473	1576-1621	-	-	31.9	2.5	1.8	.28	.09	1.27	.01	<.01	.005	<.0009	.0016	<.02
526	465	1576-1621	-	63	32.5	.6	2.4	.61	.44	<.20	.34	<.03	-	-	-	-
13	474	1576-1621	-	-	32.8	3.0	2.2	.25	.07	.30	.01	.01	.007	<.0011	<.0007	.03
411	482	1621-28	-	66	31.4	.0	1.7	.60	.06	.41	<.05	<.03	-	-	-	-
12	481	1621-28	-	-	33.8	.9	5.2	.41	.12	.30	.06	.03	.006	.0030	<.0006	<.02
9	486	1628-46	-	63	36.0	.1	.7	.32	.08	<.20	<.05	<.03	-	-	-	-
8	484	1628-46	-	55	36.9	.1	6.3	1.70	.29	<.20	<.05	<.03	-	-	-	-
10	483	1628-46	-	-	40.2	.2	1.8	.50	.55	.13	.11	.04	.008	<.0013	<.0008	<.03
7	485	1628-46	-	-	40.8	<.1	.3	.42	.11	.42	.08	.01	.017	.0019	<.0008	<.03
1	500	1646-53	-	-	21.8	2.1	8.0	.42	.25	.35	.08	.05	.019	<.0010	<.0006	.03
2	499	1646-53	-	-	24.6	3.1	7.5	.54	.21	.45	.08	.05	.018	<.0015	<.0009	.05
3	498	1653-57	-	-	24.4	2.1	6.8	.49	.37	.37	.09	.08	.017	<.0014	<.0009	.09
4	497	1653-57	-	-	26.5	1.6	6.2	.55	.66	.40	.08	.05	.020	<.0011	<.0007	.05
5	502	1657-62	-	65	20.8	2.7	9.9	.58	.54	.28	.07	.04	-	-	-	-
6	501	1657-62	-	-	21.1	2.6	8.4	.50	.52	.39	.08	.05	.013	<.0011	<.0006	.05
42	504	1662-1723	Early	-	21.8	1.8	7.2	.54	.88	.40	.10	.06	.018	<.0007	<.0004	.05
41	503	1662-1723	Early	-	21.9	1.8	6.8	.56	.70	.39	.09	.06	.018	<.0010	<.0006	.03
43	505	1662-1723	Early	61	29.8	1.2	6.7	.87	.27	<.20	.07	.03	-	-	-	-
44	506	1662-1723	Early	61	30.4	1.3	6.4	.88	.28	.22	<.05	.03	-	-	-	-
46	508	1662-1723	Middle?	65	33.9	.0	.7	.07	<.05	<.20	<.05	<.03	-	-	-	-
52	514	1662-1723	Middle	-	34.6	.5	2.0	.35	.13	.15	.03	.03	.006	.0013	<.0006	<.02
49	511	1662-1723	Middle	-	34.6	.9	4.2	1.31	.21	.21	.04	.04	.011	<.0018	.0032	.08
50	512	1662-1723	Middle	63	35.6	.0	.9	.25	<.05	<.20	<.05	<.03	-	-	-	-
45	507	1662-1723	Middle?	-	35.6	<.1	1.3	.47	.06	.17	.02	.03	.009	.0029	.0017	.05
51	513	1662-1723	Middle	-	37.6	.2	1.0	.76	.03	.22	<.01	.01	.007	.0016	.0027	<.02
47	509	1662-1723	Late	66	33.1	.0	.7	.09	<.05	<.20	<.05	<.03	-	-	-	-
53	515	1662-1723	Late	-	35.1	.2	.6	1.60	<.03	.16	.01	.04	.008	.0027	.0095	<.03
55	517	1662-1723	Late	63	35.7	.0	.7	.33	<.05	<.20	<.05	<.03	-	-	-	-
48	510	1662-1723	Late	-	36.6	.2	1.1	.49	.05	.14	.01	.03	<.008	.0014	.0027	.04
54	516	1662-1723	Late	-	36.8	<.1	.9	.38	<.02	.13	<.01	.04	.007	.0034	.0007	.04
56	518	1662-1723	Late	-	41.1	<.1	.6	.50	.03	.09	.01	.03	.006	.0015	.0030	<.02
58	525	1723-36	Early	61	37.4	.0	1.5	.31	.08	<.20	<.05	<.03	-	-	-	-
57	524	1723-36	Early	-	37.8	<.1	1.5	.28	.02	.11	.04	.02	.005	.0077	<.0005	.03
160	527	1723-36	Late	63	35.7	.0	1.1	.29	.12	<.20	<.05	<.03	-	-	-	-
59	526	1723-36	Late	-	36.9	<.1	.8	.39	.07	.12	.01	.04	.004	.0051	<.0004	<.02
63	535	1736-96	Early	60	29.6	3.0	6.6	.40	.09	<.20	<.05	<.03	-	-	-	-
61	533	1736-96	Early	-	36.5	.1	.8	1.36	.13	.34	.01	.04	<.005	.0340	.0095	<.02
62	534	1736-96	Early	-	39.2	<.1	.5	.47	<.02	.09	.01	.03	.006	.0283	.0006	<.02
64	536	1736-96	Middle	57	32.4	2.1	7.8	.31	.18	<.20	<.05	.04	-	-	-	-
65	537	1736-96	Middle	-	33.6	1.7	6.6	.43	.16	.16	.02	.04	.009	<.0016	<.0009	.05
66	538	1736-96	Middle	-	34.0	1.7	7.5	.51	.11	.51	.02	.04	<.006	.0015	.0019	<.02
68	540	1736-96	Late	59	32.1	1.9	4.5	1.20	1.00	.21	.05	<.03	-	-	-	-
67	539	1736-96	Late	-	32.4	1.4	6.9	1.76	1.22	.44	.12	.05	.029	.0029	.0017	.06
70	542	1736-96	Late	-	33.3	1.9	7.7	1.12	.14	.21	.03	.05	.005	.0012	.0052	<.02
69	541	1736-96	Late	-	35.7	1.9	3.3	.59	.19	.42	.02	.07	<.006	.0010	.0011	<.02
71	543	1736-96	Late	54	35.7	1.5	5.7	1.60	.90	.20	.05	.03	-	-	-	-
72	544	1736-96	Late	54	34.2	1 5	6.0	2.55	.77	.11	.04	.02	.011	.0031	.0015	.06
76	548	1796-1821	Early?	56	33.7	1.1	7.3	1.12	.57	.29	.09	.03	-	-	-	-
75	547	1796-1821	Early?	61	33.4	<.9	3.4	I.01	1.73	.43	.13	.04	.022	.0027	<.0022	.15
73	545	1796-1821	Late?	58	36.0	.1	3.6	1.30	.77	.27	.06	.03	-	-	-	-
74	546	1796-1821	Late?	56	34.3	<.2	4.5	.84	.97	.54	.27	.04	.030	.0019	<.0005	.08
79	551	1821-51	Early?	57	33.1	.0	5.8	1.57	2.00	.74	.12	.05	-	-	-	-
81	552	1821-51	Early?	60	31.7	<.3	3.8	1.62	2.00	.86	.22	.04	.090	.0015	.0007	.12
77	549	1821-51	Late?	60	33.0	.0	3.7	.89	1.36	.47	.13	.05	-	-	-	-
78	550	I821-51	Late?	60	33.2	<.3	3.3	1.31	1.06	.46	.11	.04	.010	.0013	<.0007	.20
83	555	1851-62	Early?	56	34.7	.0	5.8	1.80	1.20	.82	.09	<.03	-	-	-	-
84	556	1851-62	Early?	56	36.8	.0	5.2	1.70	.17	.49	.11	.06	-	-	-	-
81	553	1851-62	Late?	55	35.9	.0	6.3	1.70	.81	.71	.13	.03	-	-	-	-
82	554	1851-62	Late?	57	36.9	<.3	3.2	1.82	.59	.48	.09	.06	.048	.0006	<.0007	.08
86	559	1862-75	-	-	36.5	1.4	4.3	1.60	.44	.47	.17	.07	.036	.0019	.0011	.04
187	560	1862-75	-	-	40.3	.1	1.8	3.00	.11	.26	.14	.02	.048	.0011	<.0005	<.02
91	463	1875-1909	-	57	32.8	.5	6.5	2.10	.50	.25	.07	<.03	-	-	-	-
90	464	1875-1909	-	57	33.9	.4	5.5	1.80	.59	.45	.07	.04	-	-	-	-
88	461	1875-1909	-	57	36.5	.2	4.7	.68	.13	.54	<.05	<.03	-	-	-	-
89	462	1875-1909	-	52	40.8	.3	4.8	1.70	.14	.31	<.05	<.03	-	-	-	-
95	468	1909+	-	57	34.1	.4	5.9	1.80	.55	.31	.07	<.03	-	-	-	-

Cast Iron Coins of Song Dynasty China: A Metallurgical Study

Michael L. Wayman and Helen Wang

Abstract
A selection of 37 Song dynasty Chinese cast iron coins was subjected to metallurgical analysis. From inscriptions, these are dated between 1078 and 1215 AD, and the mint locations of 23 of the coins are known. All were found to be white cast irons, but they separated into two types, one with relatively high levels of silicon, phosphorus and sulphur and divorced eutectic microstructures, and the other with low levels of these three elements and ledeburitic microstructures. Those coins that were minted in Shaanxi were all found to be of the first type, while those minted in the Hubei/Anhui region to the southeast are all of the second type. On the basis of sulphur content it is believed to be likely that iron used for the first group was smelted in coal- or coke-fired blast furnaces, while the iron in the second group was smelted using charcoal. This is in general agreement with what is known of the iron industry in China during the Song period.

Introduction

Analysis of objects from the past is often useful in providing information about aspects of life in earlier times and in this regard studies of coins have particular advantages. The date and location data they can convey, combined with the results of metallurgical analysis, have the potential to offer information that is important and relevant far beyond the field of numismatics. In the present work the main concern is with metallurgical and processing issues.

Here a selection of 37 Song dynasty cast iron coins from the collections of the Department of Coins and Medals, British Museum has been subjected to metallurgical analysis. The coins range in date from the 11th to the 13th centuries AD, but it is possible from the coin inscriptions to establish to within a few years the dates of the individual coins and in some cases to determine the locations of the mints where they were produced. Although based on a limited number of coins, the study allows an initial investigation of the production processes of cast iron and of iron coins, including chronological and geographical differences. These touch on specific questions, relating to:

- the characteristics of the cast iron used for coinage;
- the iron production processes used;
- the technology of coin production operations, including any heat treatment and/or mechanical processing carried out after casting;
- chronological, geographical and mint variations among the coins;
- comparison of Song dynasty coin-casting technology with contemporary Chinese non-coin cast ironwork.

Of course, metallurgical analysis of a much larger number of coins would be necessary to address these questions comprehensively; furthermore the methodology could potentially be extended to include issues such as comparisons with cast iron coins and non-coin ironwork from other regions of East and Southeast Asia.

This paper presents the Song dynasty coins in historical context, and the results of their analyses along with a discussion of those results and their possible significance.

Song dynasty iron coins

Although the vast majority of Chinese coins through the ages were cast in bronze or brass, small quantities of iron coins are known to have been made at least as early as AD 24,[1] and then during the Tang dynasty (AD 618–907) and the Five Dynasties period (AD 907–960). However, iron coin production became much more commonplace during the Song dynasty (AD 960–1279), when rapid commercial growth created a demand for large amounts of money.[2] Shortages of raw materials, such as the copper and tin needed to make bronze, are believed to be one of the major factors that stimulated the production of cast iron coinage. The advantages of using iron are obvious: iron ore was widely available, and cast iron is cheaper to produce than bronze. On the other hand their poor resistance to corrosion in many environments and the relative difficulty of obtaining a fine impression has kept iron from becoming a viable competitor to copper-based coinage materials under most sets of circumstances. There was a well-developed iron industry in China, as well as a long history of fine casting, and the technology for casting bronze coins could be applied to the casting of iron coins.

Iron coin production in Song dynasty China was neither homogeneous nor static. In general, it appears that during the Northern Song period (AD 960–1127) mints in different localities produced either bronze coins or iron coins, and in some cases both.[3] During the Southern Song period (AD 1127–1279) iron coins were circulated predominantly in Sichuan Province.

The volume of coin production also varied over time. The most intense period of coin production was the Yuanfeng reign period (1078–1085), during which the annual output has been estimated at over 5 million strings of bronze coins and 1 million strings of iron coins, with each string nominally holding 1,000 coins. There were during this period 17 inspectorates (mints) for bronze coins and nine for iron coins; of the latter six were located in Shaanxi and three in Sichuan.[4] Coin production dropped dramatically during the Southern Song period, in part because of the use of paper money.

Of the 37 Song dynasty iron coins selected for this study, 11 date from the Northern Song period and 26 from the Southern Song. The physical dimensions of the coins are given in **Table 1**. On the obverse of each coin is a four-character inscription. The first two characters indicate the reign period during which it was issued, localizing the date to within a 5–15 year period.[5] The second two characters read '*tongbao*', '*yuanbao*' or '*xinbao*', literally 'circulating treasure' or 'first treasure' or 'new treasure',

Table 1 Coin data and dimensions

Coin	BM Reg. no.	Reign period & issue	Mint mark	Reign period	Coin date	Mass (g)	Rim thickness (mm)	Coin diameter (mm)	Hole size (mm)
Northern Song									
cm7	1985.10-32.11	Yuanfeng Tongbao	-	1078-1085	-	11.54	2.5	33.6	6.8
cm8	1983.10-15.12	Yuanfeng Tonghao	-	1086-1093	-	12.95	2.8	34.4	7.2
cm9	1985.10-32.12	Yuanfeng Tongbao	-	1086-1093	-	13.04	2.9	32.5	7.2
cm10	1983.6-19.82	Zhenghe Tongbao	-	1111-1117	-	4.50	1.9	25.6	6.2
cm11	1985.10-32.28	Zhenghe Tongbao	-	1111-1117	-	8.87	2.5	31.4	6.7
cm12	1979.3-4.7	Xuanhe Tongbao	shaan	1119-1125	-	2.89	1.3	24.5	6.5
cm13	1883.7-1.899	Xuanhe Tongbao	shaan	1119-1125	-	3.49	1.2	25.1	6.5
cm17	1882.6-1.251	Xuanhe Tongbao	shaan	1119-1125	-	3.99	1.7	25.3	6.2
cm14	1985.10-32.33	Xuanhe Tongbao	shaan	1119-1125	-	4.25	1.7	25.3	6.1
cm15	1983.6-19.83	Xuanhe Tongbao	shaan	1119-1125	-	4.01	1.6	25.0	6.2
cm16	1985.10-32.32	Xuanhe Tongbao	shaan	1119-1125	-	3.99	1.9	25.3	5.9
Southern Song									
cm18	1972.8-8.39	Qiandao Yuanbao	-	1165-1173	-	6.69	2.1	28.2	7.6
cm2	1983.6-19.84	Chunxi Yuanbao	dot in crescent	1174-1189	1174-1179	5.92	1.9	31.6	8.7
cm3	1972.8-8.42	Chunxi Yuanbao	-	1174-1189	1174-1179	5.61	1.9	31.6	8.5
cm19	1972.8-8.40	Chunxi Yuanbao	dot in crescent	1174-1189	1174-1179	8.04	2.1	31.8	8.4
cm2O	1983.6-19.85	Chunxi Yuanbao	-	1174-1189	1174-1179	4.31	2.0	26.8	6.8
cm21	1972.8-8.41	Chunxi Yuanhao	-	1174-1189	1174-1179	7.55	2.0	31.5	8.2
cm3O	1987.1-9.69	Chunxi Yuanbao	chun	1174-1189	1174-1179	6.73	2.1	27.7	6.6
cm33	1987.11-11.25	Chunxi Yuanbao	tong	1174-1189	1174-1179	6.57	2.0	29.4	6.3
cm32	1987.1-9.80	Chunxi Yuanbao	tong 12	1174-1189	1185	7.36	2.1	27.7	6.0
cm31	1987.1-9.75	Chunxi Yuanbao	chun 15	1174-1189	1188	6.87	2.1	27.7	7.0
cm34	1987.1-9.87	Shaoxi Tongbao	chun 1	1190-1194	1190	7.28	2.2	27.1	6.5
cm35	1987.1-9.88	Shaoxi Tongbao	chun 2	1190-1194	1191	6.70	2.1	28.5	5.6
cm36	1987.1-9.90	Shaoxi Tongbao	tong 2	1190-1194	1191	6.59	2.0	27.2	5.9
cm37	1996.2-17.697	Shaoxi Tongbao	tong 5	1190-1194	1194	6.70	2.1	29.1	6.1
cm6	1972.8-8.48	Qingyuan Tongbao	-	1195-1200	-	8.40	2.3	30.5	7.7
cm1	1979.2-30.2	Qingyuan Tongbao	-	1195-1200	-	5.24	1.9	29.0	6.5
cm28	1987.1-9.111	Jiading Tongbao	han I	1208-1224	1208	7.21	2.2	27.8	5.3
cm29	1987.1-9.112	Jiading Tongbao	han 2	1208-1224	1209	8.08	2.3	27.9	4.9
cm22	1987.11-11.41	Jiading Tongbao	chun 2	1208-1224	1209	6.95	2.1	28.3	5.9
cm26	1987.1-9.109	Jiading Tongbao	tong 2	1208-1224	1209	7.02	2.2	28.4	6.1
cm5	1972.8-8.47	Jiading Xinbao	3	1208-1224	1210	11.25	2.9	34.3	9.5
cm27	1987.1-9.110	Jiading Tongbao	tong 3	1208-1224	1210	7.45	2.3	27.9	6.1
cm4	1972.8-8.45	Jiading Yuanbao	chun 3	1208-1224	1210	6.99	2.4	30.0	7.9
cm23	1987.11-11.42	Jiading Tongbao	chun 3	1208-1224	1210	6.04	2.0	27.8	6.0
cm24	1987.11-11.43	Jiading Tongbao	chun 4	1208-1224	1211	7.13	2.2	28.8	6.1
cm25	1987.11-11.44	Jiading Tongbao	chun 8	1208-1224	1215	7.08	2.5	27.0	6.7

respectively (**Fig. 1**). On the reverse of some coins there is a one or two character inscription indicating the year of the reign period in which it was issued, and/or the mint where it was produced. For example the numeral 5 on a coin of the Shaoxi reign period (AD 1190–94) refers to year 5 of that period (AD 1194). In the case of the Chunxi reign period (AD 1174–89), year numbers were given to coins beginning in year 7 (AD 1180) so coins without numbers are taken as being within the range AD 1174–79.

Figure 1 *Jiading tongbao* coin. The front (right) has a four-character inscription *Jia ding tong bao* arranged top-bottom-right-left around the square hole. *Jiading* identifies the reign period, *tongbao* means 'circulating treasure'. The back (left) has a two-character inscription *chun er* arranged above and below the hole.

Experimental procedure

Examinations were carried out using optical and scanning electron metallography to characterize the microstructures of the coins. Compositional information was obtained by energy-dispersive X-ray microanalysis (EDX) in the scanning electron microscope (SEM). The coins were also subjected to X-radiography. Air path energy-dispersive X-ray fluorescence analysis (XRF) was used as required.

The cutting of metallographic cross-sections in order to characterize the material was not permitted in the case of these coins, which have display and study value as part of a museum collection. As a result, analysis was carried out on a flat surface prepared (as described below) on the rim of each coin. However, it was first necessary to evaluate whether metallographic analyses carried out on the prepared rim flats of the coins gave results, both compositions and microstructures, comparable with bulk characterizations obtained on the coin cross-sections. This evaluation was accomplished by examining both the prepared rim surfaces and the bulk cross-sections of four selected iron coins. Three of these were Song dynasty Chinese coins that were already in a damaged condition, so that it was permissible to cut bulk samples from them as well as to examine their rim surfaces, while the fourth was an 18th-century Japanese cast iron coin, then in a private collection and later donated to the Museum collection.[6] For bulk analysis, two of these coins were sectioned completely across their cross-sections (from the outer rim to the central square hole) while wedge-shaped sections were cut inwards from the rims of the other two. Metallurgical analyses were then carried out on these cut sections and the results compared with the results of similar analyses carried out on prepared rim flats on the same coins.

After completing these preliminary investigations, which showed that the rim analyses were indeed sufficiently representative to be utilized with confidence, a further 34 coins were analysed, all on their rim surfaces.

To prepare an area on the rim for metallography, each coin was held in a purpose-built brass jig equipped with hard rubber padding to prevent gripping-damage. With the coin held firmly in the jig, a location on the rim of the coin was then abraded on silicon carbide grit paper using water lubrication and cooling. In most cases only a fine (600 grit) paper was used, however where necessary grinding started on coarser (240 or 320 grit) silicon carbide grinding paper and progressed through 400 grit to 600 grit with careful washing between stages. The grinding procedure produced a flat area a few millimetres in length across the full width of the coin rim.

With the coin still held in the jig, metallographic polishing of the flat area was then carried out on a polishing wheel rotating at 250 rpm, first using 6 μm diamond paste on a nylon cloth and then 1 μm diamond paste on a short-napped cloth, in both cases employing an oil-based lubricant. When the polished rim flat had been washed thoroughly and dried, the coin was removed from the jig and examined using a Zeiss reflected light microscope and a JEOL SEM which was equipped with an Oxford Isis EDX analysis system with a Ge detector and an ultra-thin detector window. Examination in this unetched condition provided information on the presence or absence of gas and shrinkage porosity, the state of corrosion damage, and the nonmetallic inclusion abundance and distribution. Also at this stage chemical microanalysis was carried out using SEM-EDX in order to determine the bulk contents of silicon, phosphorus, sulphur and manganese as well as the compositions of the nonmetallic inclusions. The polished flats were then etched with 2% nital and re-examined using both optical and scanning electron microscopy to characterize all of the microstructural constituent phases.

Standard reference materials were also analysed for silicon, phosphorus, sulphur and manganese by performing SEM-EDX analyses under conditions identical to those used for the coins. Those used were British Chemical Standards SS 551, SS 554 and 183/3, all issued by the Bureau of Analysed Samples Ltd, and NBS 661 from the US National Bureau of Standards. This confirmed that the lower limits of detection of these elements were approximately 0.1–0.15%. The SEM-EDX results can be considered to have a precision and accuracy of ±10–20% relative to the values obtained.

Carbon contents were estimated from photomicrographs of representative areas of the etched microstructures, as SEM-EDX is not suitable for carbon determination. The relative areas of proeutectic phases and eutectic constituents were obtained by point counting, and converted to carbon content by two methods. Assuming equilibrium cooling and using the equilibrium phase diagram gave one value for carbon content. However, to allow for cooling being rapid enough that equilibrium conditions were not obtained, a second carbon content was calculated assuming that solidification occurred under equilibrium conditions but that no subsequent changes (other than the austenite-to-pearlite transformation) occurred during further cooling to room temperature. An estimated carbon content was obtained by averaging these two values, giving heavier weighting to the equilibrium value. The carbon contents thus obtained must be considered as accurate to no better than ±0.1% carbon.

Analytical results

Metallographic examination of the ground and polished rim flats showed that all of the coins have elemental compositions and microstructures that identify them unambiguously as white cast irons.

Compositions

The elements of major importance in determining the microstructures of cast irons are carbon, silicon, phosphorus, sulphur and manganese. The contents of the last four of these elements in the coins as determined using SEM-EDX are presented in **Table 2**. Detection limits for these elements are in the order of 0.1%, so concentrations less than this amount would not have been detected; these cases are reported in the Table as 'nd'. The carbon contents were estimated as described above.

Silicon is present at detectable levels in some coins, with contents up to about 0.8% (**Table 2**). Microanalysis showed that the silicon is localized in the pearlite constituent of the microstructure, having been in solution in the austenite at high temperatures. The phosphorus content also varies among the coins, up to a maximum of about 1.7% (note that this is very high by modern standards). The phosphorus is present in the microstructure as steadite, the binary or ternary eutectic constituent (i.e. the iron-iron phosphide eutectic mixture or the iron-iron phosphide-iron carbide eutectic mixture respectively).

The observed range of sulphur content as measured by SEM-EDX in these coins extends to slightly above 2%S, also far above levels in modern irons. Sulphur occurs in these cast irons in the form of sulphide inclusions in the microstructure; the sulphur contents in the iron matrix between the inclusions are below detection limits. The relative abundances of the sulphide particles as observed metallographically are in accord with the measured sulphur contents and correlate well with the two types of microstructure observed, ledeburitic and divorced eutectic, as will be discussed below.

Manganese was detected in only one of these coins (cm11) where the manganese content is about 0.3% and the sulphide inclusions were found to be mixed manganese-iron sulphides averaging more than 25%Mn. In all the other coins it must be present in amounts less than about 0.1%, its detection limit in the SEM-EDX system.

Other than in coin cm11, the sulphide inclusions are iron sulphides containing minor amounts of manganese (up to 5%) and titanium (up to 0.5%). However, two of the coins, cm7 and cm12, also contain appreciable amounts of copper in some of the sulphide particles. These particular sulphide inclusions could be seen in the SEM to consist of two phases, the brighter of which contains as much as 20% copper. The sulphide particles in some of the other coins contain smaller (less than 1%) amounts of copper or vanadium.

Coin cm12 was observed to have a brassy colour, unlike any of the other coins, and XRF analysis showed that indeed a layer of brass containing approximately 70% copper and 30% zinc is present on the surface of this coin. The XRF spectrum exhibited strong iron peaks emanating from the base iron beneath the brass layer, showing that the brass layer is thin, likely of the order of a few tens of micrometres. Microscopical study of the surface of this particular coin showed that its topography is rough, as is usual in iron objects that have undergone surface corrosion, and that the brass layer is on the outer surface, i.e. on top of the corrosion layer. This was confirmed by examination of the edges of the ground and polished flat area of the coin rim, which revealed the brass layer in cross-section. These observations show that the brass layer must have been applied *after* the coin corroded, and so the brass layer must be unrelated to the original manufacture of the coin. The history of this particular coin is unknown, as it was an anonymous donation to the Museum. This is a very curious effect. It is conceivable that the brass layer could have been inadvertently deposited during electrochemical cleaning in an electrolyte containing copper and zinc ions, or possibly it was deliberately electroplated for unknown reasons. In any event this plating was certainly done in the relatively recent past, perhaps for collecting purposes. Song dynasty coins were still in use in the early 20th century.

Microstructures

No graphite was observed in any of the microstructures; the presence of graphite would have identified the materials as grey or mottled cast iron. Instead, although there were microstructural differences among the coins, all had white cast iron microstructures, i.e. mixtures of cementite and pearlite, with a range of morphologies as described below.

The details of the microstructures are given in **Table 3**, where it can be seen that the coins can be grouped into two major microstructural categories. One of these, termed 'ledeburitic', had a matrix of ledeburite (the eutectic constituent which consists of cementite and austenite, the latter typically having transformed to pearlite during cooling) with varying amounts of the proeutectic phases pearlite or cementite. Thus, for example, the microstructures of some coins contained only ledeburite (**Fig. 2**), while others consisted of a matrix of ledeburite with various amounts of proeutectic pearlite (**Figs 3 and 4**) or proeutectic cementite (**Fig. 5**). This type of microstructure is typical of the solidification of eutectic and near-eutectic alloys, as described in the Discussion section below. The other type of microstructure observed, termed 'divorced eutectic', consisted of a matrix of cementite in which are embedded pearlite dendrites (**Figs 6 and 7**). In these coins the pearlite dendrites occupied between 45% and 80% of the microstructure, the balance being cementite. Two of the coins, cm4 and cm11, did not fall clearly into either group, as they had microstructures which were mixtures of the two main types.

In addition to the phases described above, several other microconstituents were observed to be present to varying extents within the microstructures of the coins (see **Table 3**). Notable among these are the phosphorus-bearing constituent steadite. Both the two- and three-phase eutectic mixture described above have melting temperatures below 1,000°C and hence they are invariably found in the last regions of the microstructure to solidify, i.e. at the boundaries of the ledeburite colonies in the ledeburitic microstructures and between the proeutectic pearlite dendrites or ledeburite laths in the divorced eutectic microstructures. Steadite was observed in most of the coins; its relative abundance, as reported in **Table 3**, agreed well with the phosphorus contents of the coins as measured by EDX.

Another commonly observed microstructural constituent was inclusions of iron sulphide, some of which contained manganese as mentioned above. These sulphide particles (visible for example in **Fig. 7**, where they appear as light grey blobs within the cementite) were found to be especially abundant in some coins and absent or extremely rare in others, as reported in **Table 3**. The observed abundances of sulphide inclusions in the microstructures were found to be higher in coins with higher measured sulphur contents (**Table 2**), as expected, and furthermore there is a striking correlation between sulphur content (or sulphide particle abundance) and microstructural category. Thus the sulphur content in the ledeburitic coins was below detection limits, in sharp contrast to the levels in the divorced eutectic coins. Like the steadite, the sulphide particles are found at interdendritic locations since during solidification the sulphur, like the phosphorus, is concentrated in the liquid between the proeutectic constituents.

Along with the various metallurgical phases and constituents mentioned above, two types of porosity were observed in these coins, gas porosity and shrinkage porosity. Gas porosity, which occurs as spherical bubbles, arises when gases that are dissolved in the liquid iron are precipitated during solidification as a result of their having much smaller solubilities in solid iron than in the liquid. In contrast, shrinkage porosity is a consequence of the solid material occupying less volume than the liquid so that as the microstructural constituents grow together during solidification there is insufficient liquid metal available to form a space-filling metallic structure. The result is that gaps are left between the constituents, i.e. on the boundaries between the solidification colonies.

Gas porosity was observed to be present at a macroscopic scale in the form of spherical holes (**Fig. 8**), many of which had become filled, or partially filled, with corrosion products. In addition, gas porosity on a finer scale (microporosity) occurred in most of the coins in the form of spherical holes about 1 μm in diameter associated with the interdendritic constituents, typically the sulphide inclusions; some of this microporosity can be seen in **Figure 7**. Shrinkage porosity was present in all of the coins. In those coins that had ledeburite in the microstructure, the shrinkage porosity was manifest as gaps or irregular holes in the material at ledeburite colony boundaries (**Fig. 8**).

X-radiography clearly revealed the macroscopic (0.1–1 mm diameter) gas porosity in the form of small dark circular markings on the X-ray film (**Fig. 9**). Some coins, notably cm37, displayed very considerable amounts of coarse gas porosity. The porosity in coin cm5 was so extensive in the region where its cross-section was sampled that the coin appeared to be hollow; this was also visible in the radiograph. In this case the porosity was too great to be due to either shrinkage or gas, and is attributed to liquid metal feeding problems during the casting process, either because of poor mould gating system design, inadequate pouring temperature or some inadvertent restriction on metal flow into the mould.

Corrosion was also visible in most of the microstructures, having penetrated from the surface into the interiors of the coins

Figure 2 Fully ledeburitic microstructure (cm31). Nital etch. Scale bar 50 microns

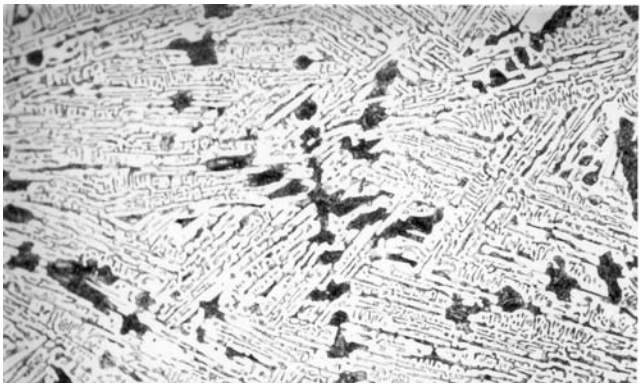

Figure 3 Microstructure of ledeburite with 10% proeutectic pearlite (cm32). The pearlite appears dark but close examination shows it to be lamellar ferrite and cementite. Nital etch. Scale bar 50 microns

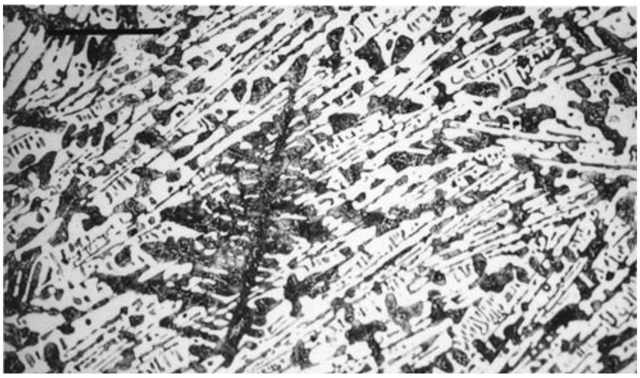

Figure 4 Microstructure of ledeburite with 25% proeutectic pearlite (cm29). Nital etch. Scale bar 50 microns

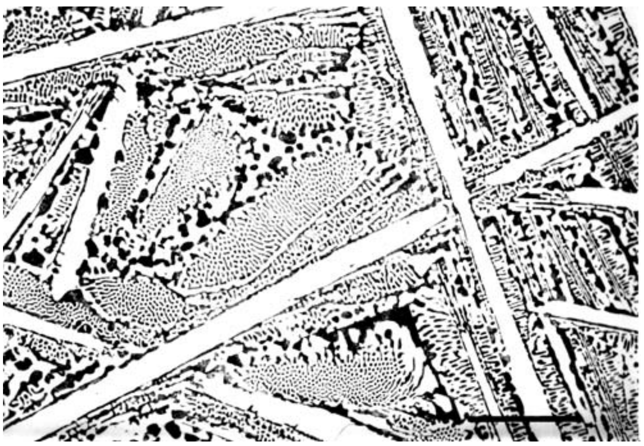

Figure 5 Microstructure of ledeburite with 20% proeutectic cementite in the form of laths (cm24). Nital etch. Scale bar 50 microns

Figure 6 Divorced eutectic microstructure with 50% proeutectic pearlite dendrites in a cementite matrix (cm12). Nital etch. Scale bar 50 microns

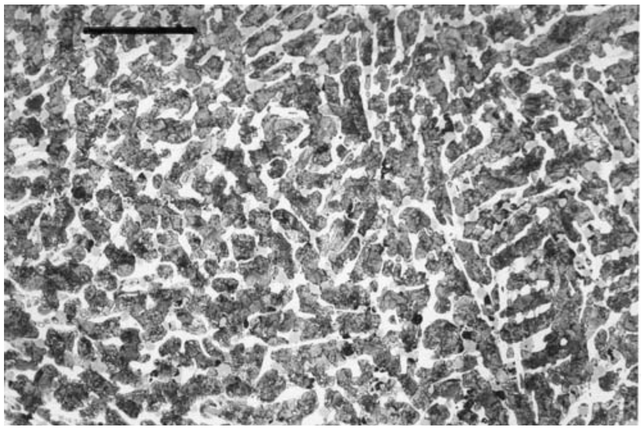

Figure 7 Divorced eutectic microstructure with 75% proeutectic pearlite dendrites in a cementite matrix (cm10). Nital etch. Scale bar 50 microns

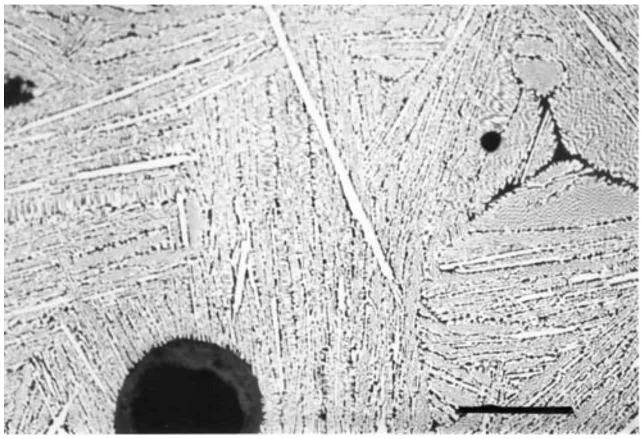

Figure 8 Ledeburitic microstructure with proeutectic cementite, showing gas porosity (spherical voids) as well as shrinkage porosity (dark irregular voids between ledeburite colonies) (cm28). Nital etch. Scale bar 50 microns

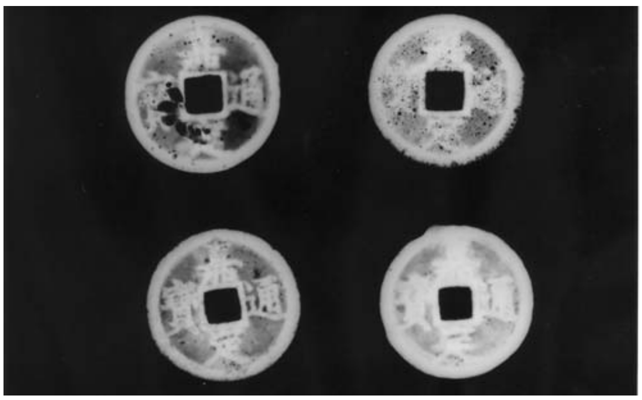

Figure 9 X-radiographs of four coins showing variable degrees of casting porosity. Clockwise from upper left cm26, cm27, cm29, cm28

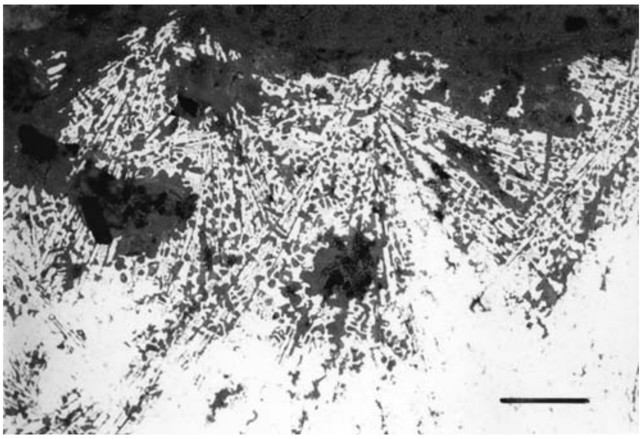

Figure 10 Corroded microstructure at the edge of a coin (cm11). The cementite remains white while the ferrite has corroded and now appears grey. Unetched. Scale bar 100 microns

(**Fig. 10**), sometimes reaching or surpassing the midpoint of the cross-section. The pearlite constituent was attacked preferentially by the corrosion (i.e. pearlite was anodic in the corrosion reaction), so that the as-polished (i.e. unetched) surface of the corroded area showed surface relief with the cementite standing proud (the corrosion products having been spalled from the surface during grinding and polishing). Hence the microstructure could be clearly seen and identified in corroded areas even without etching. The corrosion of the pearlite, especially in the ledeburitic constituent, also created high stress concentrations in the corroded area making the coins more susceptible to fracture, thus it was necessary to use extra care in handling the most heavily corroded coins. As corrosion progressed further, the cementite also corroded; at this stage the sulphide particles and sometimes traces of relict cementite could be discerned within the corrosion products. Where corrosion was severe no vestiges of the original microstructure remained.

Discussion

Early examples of cast iron, white, mottled or grey, are found only rarely outside China, and then usually either as apparently inadvertent products of bloomery furnace operation or as intermediate furnace products, i.e. pig iron intended for conversion into wrought iron. In China, however, cast iron tools and agricultural implements became common from about the mid-1st millennium BC.[7] Chinese cast iron coinage appeared at least as early as the Han period, but only became commonplace between the 11th and 13th centuries AD. In some respects, white cast iron is an appropriate material for coins, at least for cast coins, since it is hard, has good wear resistance in the as-cast condition, and has acceptable casting properties, particularly when its phosphorus content is high. Furthermore, and most importantly, it is economically attractive, especially in comparison with other common coinage alloys such as bronze. Although white cast iron is a brittle material, the coins can be made with a thickness sufficient to keep applied stresses acceptably low, so that fracture in service should not normally be a problem. On the other hand white cast iron has comparatively high levels of solidification shrinkage, thus it reproduces mould features relatively poorly.

The elemental compositions of the coins reported in **Table 2** were not unexpected. All of the analysed elements, in conjunction with cooling rate, play major roles in determining the characteristics of the cast iron. The coins displayed an appreciable range of carbon contents, from about 2.3% to 4.9%, close to the full range normally associated with cast irons. Significant variability was also found in the contents of silicon, phosphorus and sulphur in these coins, with maxima for the three elements at 0.78%Si, 1.65%P and 2.05%S. These compositions explain why all the observed microstructures were those of white cast iron. At similar cooling rates, white cast iron is formed in irons that have low values of Si and C and high values of S. None of the coins fell into a composition range where grey cast iron would have been expected. For example, iron containing carbon above 3%, silicon above 1% and sulphur below 0.1% would be expected to solidify as grey cast iron, but none of these coins came close to such a composition; none had silicon contents high enough to cause the formation of grey cast iron, and those with even moderate silicon contents also contained sufficient sulphur to more than compensate for the silicon. Their compositions suggest that even at unrealistically slow cooling rates it is highly unlikely that any of these coins would have solidified as grey cast iron.

It is clear from **Table 2** that in a general way the coins could be divided into two groups, one group of 17 coins having more than 1.2% total (P+Si+S) and the other group of 20 coins having less than 0.7% total (P+Si+S). In addition, although there was a slight overlap, the carbon contents of the two groups were also different, with the first group having an average carbon content lower than that of the second. This inverse relationship with carbon content is not unexpected because silicon, phosphorus and sulphur all lower the solubility of carbon in liquid iron.

The grouping of the coins based on elemental composition, as described in the preceding paragraph, was found to correspond almost exactly with the two groups based on microstructures.

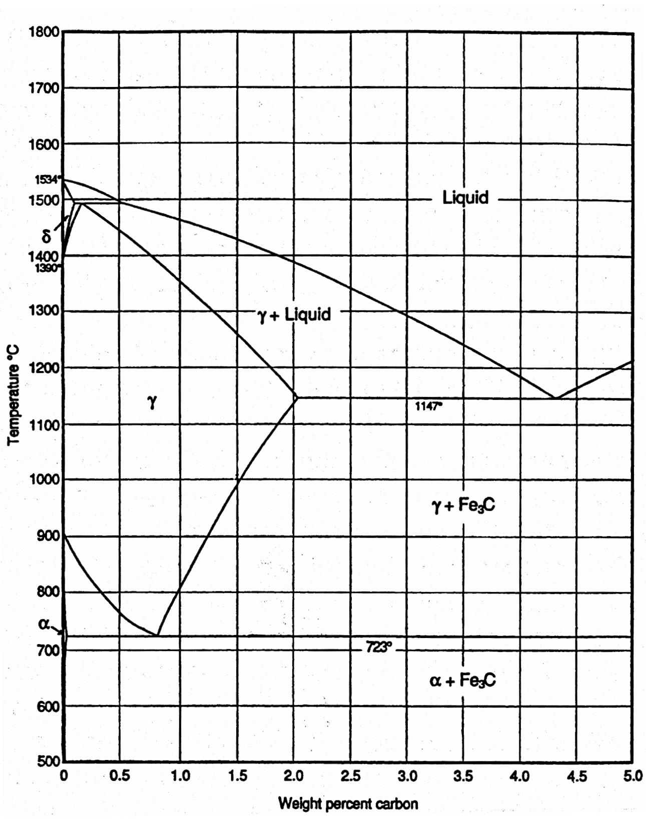

Figure 11 Iron-iron carbide (cementite) metastable phase diagram; adapted from Hansen & Anderko 1958, 354

Table 2 Coin compositions and microstructures

Coin	Reign Period	Mint mark	Date range	Coin date	Si (wt%)	P (wt%)	S (wt%)	C (wt%)*	Mn (wt%)	Microstructure
cm7	Yuanfeng	-	1078-1085	-	0.32	0.60	0.90	3.4	nd	divorced eutectic
cm8	Yuanfeng	-	1086-1093	-	0.53	0.90	0.73	3.4	nd	divorced eutectic
cm9	Yuanfeng	-	1086-1093	-	0.70	1.38	1.06	3.1	nd	divorced eutectic
cm10	Zhenghe	-	1111-1117	-	0.71	0.79	1.71	2.6	nd	divorced eutectic
cm11	Zhenghe	-	1111-1117	-	0.20	0.30	0.15	3.1	0.31	mixed
cm12	Xuanhe	shaan	1119-1125	-	0.25	0.58	0.39	4.0	nd	divorced eutectic
cm13	Xuanhe	shaan	1119-1125	-	0.57	0.69	1.65	2.3	nd	divorced eutectic
cm17	Xuanhe	shaan	1119-1125	-	0.32	0.68	0.37	4.0	nd	divorced eutectic
cm14	Xuanhe	shaan	1119-1125	-	0.78	0.71	2.05	2.3	nd	divorced eutectic
cm15	Xuanhe	shaan	1119-1125	-	0.55	0.71	1.33	2.9	nd	divorced eutectic
cm16	Xuanhe	shaan	1119-1125	-	0.57	0.73	1.14	2.9	nd	divorced eutectic
cm18	Qiandao	-	1165-1173	-	0.18	1.35	0.41	4.2	nd	divorced eutectic
cm2	Chunxi	Dot in crescent	1174-1189	1174-1179	0.25	1.48	1.97	2.6	nd	divorced eutectic
cm3	Chunxi	-	1174-1189	1174-1179	0.50	1.25	2.00	2.6	nd	divorced eutectic
cm19	Chunxi	Dot in crescent	1174-1189	1174-1179	0.36	1.36	1.35	3.7	nd	divorced eutectic
cm20	Chunxi	-	1174-1189	1174-1179	0.25	1.65	1.52	3.4	nd	divorced eutectic
cm21	Chunxi	-	1174-1189	1174-1179	0.26	1.37	1.08	4.0	nd	divorced eutectic
cm30	Chunxi	chun	1174-1189	1174-1179	0.18	0.18	nd	4.3	nd	ledeburitic
cm33	Chunxi	tong	1174-1189	1174-1179	nd	0.14	nd	4.9	nd	ledeburitic
cm32	Chunxi	tong 12	1174-1189	1185	nd	nd	nd	4.0	nd	ledeburitic
cm31	Chunxi	chun 15	1174-1189	1188	nd	0.12	nd	4.3	nd	ledeburitic
cm34	Shaoxi	chun 1	1190-1194	1190	0.16	nd	nd	3.9	nd	ledeburitic
cm35	Shaoxi	chun 2	1190-1194	1191	nd	0.15	nd	4.2	nd	ledeburitic
cm36	Shaoxi	tong 2	1190-1194	1191	0.16	0.10	nd	4.0	nd	ledeburitic
cm37	Shaoxi	tong 5	1190-1194	1194	nd	nd	nd	4.3	nd	ledeburitic
cm6	Qingyuan	-	1195-1200	-	nd	0.31	nd	4.0	nd	ledeburitic
cm1	Qingyuan	-	1195-1200	-	0.13	0.13	nd	4.3	nd	ledeburitic
cm28	Jiading	han 1	1208-1224	1208	nd	0.22	nd	4.5	nd	ledeburitic
cm29	Jiading	han 2	1208-1224	1209	nd	0.16	nd	3.6	nd	ledeburitic
cm22	Jiading	chun 2	1208-1224	1209	0.10	0.18	nd	4.8	nd	ledeburitic
cm26	Jiading	tong 2	1208-1224	1209	nd	nd	nd	4.3	nd	ledeburitic
cm5	Jiading	3	1208-1224	1210	nd	0.25	nd	3.9	nd	ledeburitic
cm27	Jiading	tong 3	1208-1224	1210	nd	nd	nd	4.3	nd	ledeburitic
cm4	Jiading	chun 3	1208-1224	1210	0.38	0.18	0.65	3.4	nd	mixed
cm23	Jiading	chun 3	1208-1224	1210	0.14	0.12	nd	4.5	nd	ledeburitic
cm24	Jiading	chun 4	1208-1224	1211	0.13	0.16	nd	4.8	nd	ledeburitic
cm25	Jiading	chun 8	1208-1224	1215	0.13	nd	nd	3.9	nd	ledeburitic

Notes: nd = not detected; * carbon content estimated as described in text

All of the 19 coins with total (P+Si+S) contents below 0.5% had ledeburitic microstructures, while the 16 coins with high values of (P+Si+S) content all had divorced eutectic microstructures. The two coins that were observed to have mixed microstructures, i.e. ledeburite together with divorced eutectic, were intermediate between the two groups on the basis of elemental composition as well as on the basis of microstructure. The origins of these types of microstructure will now be explained and then the two coin groups can be discussed further.

Explanation of observed microstructures

The microstructural characteristics of the Song coins can be explained with reference to the Fe–Fe_3C equilibrium phase diagram (**Fig. 11**). According to this diagram, when a molten iron-carbon alloy containing 4.3% carbon (the eutectic composition) solidifies under equilibrium (slow) cooling conditions it should transform at the eutectic temperature, 1150°C, to a two-phase eutectic mixture of cementite (Fe_3C) and austenite (γ-iron) known as ledeburite. Ledeburite is not strictly lamellar, as are many eutectic microconstituents, but rather it consists of plates of cementite interspersed with branched linear arrays of austenite whose branches often run at high angles to the direction of growth of the ledeburite colony. Furthermore these branches do not fill the entire space between the cementite plates, but some cementite infill forms along with the austenite branches, resulting in the distinctive ledeburite morphology. On continued slow cooling, the solid austenite rejects carbon, so that the amount of cementite increases, via the growth of pre-existing cementite as well as, possibly, the precipitation of cementite plates within austenite grains. On cooling through the eutectoid temperature (725°C) the remaining austenite transforms to pearlite, creating the final microstructure since no further changes are expected during further cooling to ambient temperature. This is the simplest form of the microstructure referred to here as ledeburitic, which is exemplified by **Figure 2**.

Cooling of liquid cast irons with carbon slightly below the eutectic composition causes the formation of proeutectic austenite dendrites in the liquid, with the remaining liquid transforming to ledeburite as described above when the eutectic temperature is reached. Subsequent cooling towards 725°C under equilibrium conditions then causes the rejection of carbon by the austenite, and thus an increase in the amount of cementite as described above. After the remaining austenite transforms to pearlite at 725°C, the final microstructure consists of pearlite dendrites in a background matrix of ledeburite. The microstructures of coins with lower carbon contents would exhibit larger amounts of proeutectic dendrites in a ledeburite

Table 3 Details of coin microstructures

Coin	Microstructure	Proeutectic phase	Steadite (phosphorus)	Suiphide inclusions	Gas porosity
cm1-R	ledeburite	none	very little*	few	micro
cm1-X	ledeburite with a few pearlite dendrites	pearlite (1%)	very little*	few	micro
cm2	divorced eutectic pearlite with cementite	pearlite (75%)	abundant*	abundant FeS	micro
cm3	divorced eutectic pearlite with cementite	pearlite (75%)	abundant*	abundant FeS	micro
cm4	divorced eutectic pearlite with cementite and minor ledeburite	pearlite (60%)	very little*	abundant FeS	micro
cm5	ledeburite with pearlite dendrites	pearlite (15%)	present*	few	micro & micro
cm6	ledeburite with pearlite dendrites	pearlite (10%)	present*	few	macro & micro
cm7	divorced eutectic pearlite with cementite	pearlite (60%)	present*	abundant FeS	macro & micro
cm8	divorced eutectic pearlite with cementite	pearlite (10%)	present*	abundant FeS	macro & micro
cm9	divorced eutectic pearlite with cementite	pearlite (65%)	present*	abundant FeS	micro
cm10	divorced eutectic pearlite with cementite	pearlite (75%)	present*	abundant FeS	micro & micro
cm11	ledeburite and cementite with pearlite dendrites	pearlite (40%)	present*	some FeMnS	macro & micro
cm12	divorced eutectic with pearlite dendrites	pearlite (50%)	present*	some FeS	macro & micro
cm13	divorced eutectic with pearlite dendrites	pcarlite (80%)	abundant	some FeS	macro & micro
cm14	divorced eutectic with pearlite dendrites	pearlite (80%)	present*	abundant FeS	macro & micro
cm15	divorced eutectic with pearlite dendrites	pearlite (70%)	present*	abundant FeS	micro
cm16	divorced eutectic with pearlite dendrites	pearlite (70%)	present*	abundant FeS	micro
cm17	divorced eutectic with pearlite dendrites	pearlite (50%)	present*	some FeS	macro & micro
cm18	divorced eutectic with pearlite dendrites	pearlite (45%)	abundant*	some FeS	macro & micro
cm19	divorced eutectic with pearlite dendrites	pearlite (55%)	abundant*	abundant FeS	micro
cm20	divorced eutectic with pearlite dendrites	pearlite (60%)	abundant*	some FeS	micro
cm21	divorced eutectic with pearlite dendrites	pearlite (50%)	abundant*	some FeS	macro & micro
cm22	ledeburite with cementite laths	cementite (20%)	little or none	very few	macro & micro
cm23	ledeburite with cementite laths	cementite (9%)	little or none	very few	macro & micro
cm24	ledeburite with cementite laths	cementite (20%)	little or none	few	macro & micro
cm25	ledeburite with pearlite dendrites	pearlite (15%)	little or none	very few	micro
cm26	ledeburite with cementite laths	cementite (2%)	little or none	few if any	macro & micro
cm27	ledeburite	none	little or none	few if any	macro & micro
cm28	ledeburite with cementite laths	cementite (8%)	very little*	few	macro & micro
cm29	ledeburite with pearlite dendrites	pearlite (25%)	very little*	few	macro & micro
cm30	ledeburite with pearlite dendrites	pearlite (I%)	little or none	some FeS	macro & micro
cm31	ledeburite with cementite laths	cementite (1%)	little or none	few if any	macro & micro
cm32	ledeburite with pearlite dendrites	pearlite (I0%)	little or none	tiny	macro & micro
cm33	ledeburite with cementite laths	cementite (26%)	little or none	few if any	macro & micro
cm34	ledeburite with pearlite dendrites	pearlite (15%)	little or none	few and tiny	micro
cm35	ledeburite with pearlite dendrites	pearlite (6%)	little or none	some FeS	macro & micro
cm36	ledeburite with pearlite dendrites	pearlite (10%)	little or none	few and tiny	macro & micro
cm37	ledeburite	none?	little or none	few and tiny	macro & micro

Notes: cm1, 4 and 5 were sectioned. In cm1 the rim (R) and cross-section (X) showed different microstructures. In cm4 and cm5 there were no differences.
* = on colony boundaries

matrix as shown in **Figures 3 and 4**. Coins with slightly more than the eutectic carbon content would solidify in the same way except that the proeutectic phase would be cementite, which is present as plates rather than dendrites as shown in **Figure 5**. This provides an explanation for the observed microstructures of the ledeburitic group of coins.

The description of solidification outlined in the previous paragraphs is normal for alloy systems, but another possibility exists, the formation of so-called 'divorced eutectic' microstructures. These are more likely to form at compositions well above or well below the eutectic composition, and are encouraged by slower cooling rates. In the solidification of white cast irons with well below 4.3%C, the phase diagram (**Fig. 11**) predicts that significant amounts of proeutectic austenite dendrites will form in the liquid so that when the eutectic temperature is reached a relatively small amount of liquid remains between these dendrites. At the eutectic temperature this eutectic liquid freezes, but rather than this happening by the formation of austenite and cementite in the form of ledeburite, the austenite phase of the eutectic solidifies on the pre-existing austenite dendrites, causing them to grow, while the eutectic cementite precipitates in the interdendritic spaces. Hence instead of obtaining the intimately intergrown austenite and cementite mixture of phases (ledeburite), the austenite and cementite form separately (i.e. 'divorced' from each other).

As in the ledeburitic coins, subsequent cooling under equilibrium conditions from the eutectic temperature down to the eutectoid temperature (725°C) would be expected to cause some of the austenite to transform to cementite, hence the cementite in the interdendritic spaces would be expected to grow. This was observed, with significant amounts of cementite plates being present. At the eutectoid temperature, the remaining austenite transforms to pearlite, resulting in the microstructures observed (**Figs 6 and 7**).

Although not observed in any of the coins examined here, divorced eutectic microstructures can also form at hypereutectic compositions. In this case solidification occurs by the formation of proeutectic cementite plates, with the eutectic constituents again forming separately at the eutectic temperature. In this case the eutectic cementite forms on the proeutectic plates, causing their growth, and also as interdendritic laths. At the same time the austenite forms in the interdendritic spaces but not coupled with the cementite, as it is in ledeburite. Again the austenite transforms to pearlite on subsequent cooling, so that the final microstructure is a matrix of pearlite enclosing cementite plates. Examples of this process, hypereutectic white cast irons with divorced eutectic microstructures (ie with proeutectic cementite), have been observed in other ancient Chinese cast irons.[8]

Discussion of microstructures

With this background, the observed coin microstructures can be considered in more detail. Clearly the elemental compositions will have been important in determining the microstructures, and in fact a causal relationship can be seen to exist between the elemental compositions of the coins and their type of microstructure, i.e. ledeburitic *v* divorced eutectics. As described above, divorced eutectics are more likely to form when the amount of proeutectic phase is large, i.e. when the carbon content is far below or far above the eutectic. This was in fact observed, as the average carbon content of the divorced eutectic coins (**Table 2**) was found to be 3.2%, whereas the average for the ledeburitic coins was 4.2%. However, it is apparent from **Table 2** that there were a few exceptions to this trend, with several coins exhibiting divorced eutectic microstructures despite having carbon contents which were relatively high (relatively close to the eutectic composition), in conflict with expectation. The determining factor in these cases is likely to be their high phosphorus contents, as phosphorus is known to stimulate divorced eutectic microstructures in hypoeutectic white cast irons such as these.[9] The coins with divorced eutectic microstructures were all observed to have phosphorus contents above 0.58%. It is of interest in this regard to consider the microstructures of coins having the same carbon content but different phosphorus contents. Here again the results support the role of phosphorus in stimulating the divorced eutectic microstructures. For example, cm12 and cm25 both have nearly the same carbon contents however the higher phosphorus coin (cm12: 0.58%P) has a divorced eutectic microstructure while cm25, with its low (less than the detection limit) phosphorus content, is ledeburitic.

The effects of the sulphur and silicon contents on the formation of divorced eutectic microstructures in cast iron do not seem to have been reported in the literature, because both of these elements were present in the coins at levels well above the ranges exhibited by modern cast irons. It is certainly possible that one or both of these elements could complement the carbon content in stimulating the formation of the divorced eutectic. The correlation between high sulphur content and a divorced eutectic microstructure (**Table 2**) is particularly striking, with the ledeburitic microstructures having a maximum of 0.31%S and the divorced eutectics a minimum of 0.37%S (again with the exception of the mixed-microstructure coin cm11, discussed below). It is possible that along with the lower carbon and higher phosphorus contents, the higher levels of sulphur could be a factor in the development of divorced eutectic microstructures. A similar effect was noted in a group of Chinese white cast iron statuary dating from the 9th to the 19th centuries AD.[10]

Two of the coins exhibited microstructures that included both ledeburite and divorced eutectic components, being in a transition state between the two microstructural groups. One of these, coin cm11, had a ledeburitic microstructure which was not as clearly defined as the other ledeburitic structures, its appearance suggesting that it was close to the transition between ledeburite and a divorced eutectic. This is consistent with its composition, as its carbon content was low compared to the other ledeburitic coins, while its silicon, phosphorus and especially sulphur contents were low compared to the other divorced eutectic coins. The case of coin cm4 was comparable in that it was mainly a divorced eutectic but contained a small amount of ledeburite, consistent with its combination of relatively high carbon, relatively low phosphorus and relatively high sulphur.

Few analyses have been reported on other Chinese cast irons of similar or earlier date,[11] but those which do exist compare well with the compositions and microstructures of these coins. Furthermore, work currently in progress is yielding results that are also in accord with these.[12]

Smelting conditions

It is of interest to consider the extent to which the characteristics of these coins can be interpreted to yield information about the iron smelting technology. One important aspect is the question of whether the iron in these coins was smelted using coal or coke as opposed to charcoal to provide the high temperatures and reducing atmospheres needed for blast furnace operation. Although the use of mineral fuels in iron smelting was not successfully achieved in Europe until the early 18th century AD, it is clear that coal or coke was being used for smelting iron in Song times, and there are suggestions of much earlier use.[13]

Wagner has given direct consideration to the dates at which coal or coke came into relatively widespread use in iron smelting, based to some extent on early writings but also quoting the results of scientific examinations by others.[14] He quotes a text reference from the 4th century AD which seems to refer to the use of coal in iron smelting, though it is important to note that the use of coal or coke in metallurgy for purposes such as heating of annealing furnaces or baking moulds may well have preceded their use in blast furnaces by many centuries.[15] Wagner also points out that very many such references suddenly appeared in writings of Song times. Since this was a time of serious wood shortage,[16] an increased emphasis on the use of mineral fuel is not surprising. On the question of which of the mineral fuels, coal or coke, was being used, Wagner points out that coke has been used in China since very early times, and Hartwell and Golas refer to the specific use of coke in iron smelting during the Song period.[17]

The scientific evidence for the use of coal or coke referred to by Wagner includes three radiocarbon analyses obtained by Qiu Shihua and Cai Lianzhen from Song/Yuan cast iron objects which gave dates ranging between 11,500 and 14,000 years BP.[18] Wagner notes that these are far too early to be possible valid dates *per se*, and suggests that they could result from a mix of charcoal and coke/coal in the smelting furnace, although such mixed fuels are not otherwise attested. Alternative explanations for these dates without invoking the use of mineral fuel include the use of a carbonate mineral such as limestone in the flux, or possibly the use of iron carbonate ore (the carbon present in coal and in carbonates are both infinitely old from a radiocarbon perspective). However the most likely explanation for the dates is that the objects could have been cast from a second furnace in which charcoal smelted iron and coal/coke smelted iron had been remelted together. It is becoming more evident that attempts to apply radiocarbon dating to the carbon present in ferrous materials have the potential to yield erroneous results for a variety of reasons.[19]

The other scientific evidence for the use of coal or coke referred to by Wagner is the presence of sulphur in cast iron artefacts.[20] Many coals contain appreciable amounts of sulphur, most of which remains after its transformation to coke, whereas charcoal contains little or no sulphur. The smelting conditions in early blast furnaces are likely to cause the majority of this sulphur to end up in the cast iron. The most simplistic approach would therefore be to say that high sulphur content in the cast iron can be identified with a coal- or coke-burning blast furnace, whereas low sulphur content is indicative of charcoal smelted iron. This argument has been used frequently, for example by Rostoker and Bronson and also by Han Rubin who interprets a positive response to a sulphur print as evidence for the use of coal.[21]

Unfortunately, this type of argument is complicated by a number of other factors. One is that sulphur is also a constituent of some iron ores, in the form of the mineral pyrite (iron sulphide) that could contribute sulphur to the cast iron even if the iron was charcoal-smelted, although roasting of the ore prior to smelting is likely to drive off most of this sulphur. Another factor, probably of more importance, is that some coals have intrinsically low sulphur contents, so that iron smelted with these coals would not acquire high levels of sulphur. For example, if coal or coke use results in higher smelting temperatures (see below), more sulphur can be transferred to the slag phase, especially if limestone is used as a flux. This would be expected to give a sulphur level lower than in iron smelted with coke at lower temperatures, however still higher than in charcoal-smelted iron. For these reasons it cannot be said with absolute confidence that a high sulphur content in the iron is proof that the iron was smelted with coal (coke) or that low sulphur iron comes from smelting with charcoal.

However, a review of the results of previously reported chemical analyses of charcoal- and coke-smelted cast irons from early (pre-4th century AD) China and from early European blast furnace products[22] shows that although charcoal-smelted iron almost always displays low sulphur contents, i.e. below 0.1%S, and coke-smelted irons are normally well above 0.1%S, some coke-smelted cast irons do display low sulphur levels, as low as 0.05%S. On the other hand, of all of the charcoal-smelted cast irons analysed, none had sulphur levels much above 0.1% and only one was above 0.2%S, which confirms that the use of high-sulphur iron ore was not common. Thus the empirical evidence is that although a low sulphur content cannot be considered as absolute proof of the use of charcoal in iron smelting, a high sulphur content is in fact strongly indicative of the use of mineral fuel, i.e. coal or coke.

Discussion of composition

The question of furnace temperature is one that can be addressed by considering the results of the coin analyses since high silicon and manganese contents of cast iron are potential indicators of high furnace temperature. Silicon enters the iron-smelting furnace in the gangue (waste) material associated with the ore minerals, as well as being a constituent of the furnace-lining materials. The gangue, along with reacted furnace linings and fuel ash, becomes the smelting slag, and silicon partitions between metal and slag, with more silicon reduced into the metal at higher smelting temperatures. Once again, the choice of fuel plays a role. Since coal- or coke-fired furnaces can be expected to operate at higher temperatures than charcoal-fired furnaces,[23] the argument could be made that high-silicon cast irons are more likely to have been coal- or coke-smelted. However, many variables other than the fuel are involved in determining furnace temperature, notably furnace size and air blowing rate. Charcoal-fired blast furnaces can in fact be operated under conditions such that they achieve temperatures high enough to produce high-silicon cast iron.

It is of course a reasonable possibility that the iron used to make some of the coins was coke-smelted while other coins were made of charcoal-smelted iron. (In the Japanese coin analysed in the preliminary work, the iron, which was undoubtedly the product of a charcoal-fired furnace, was found to have low sulphur content). As iron smelting using coal or coke was becoming much more common during the Song dynasty, the time when these particular coins were produced, it could be expected that both charcoal- and coal/coke-fired furnaces might have been in use at the same time, possibly even in the same geographic region at the same time. Furthermore, it is not impossible that some smelting furnaces were fired using mixtures of charcoal with coal or coke, and it is even more likely that in many if not all cases the coins were cast from remelting furnaces where coal-smelted and coke-smelted irons could have been mixed. Consequently, the wide range of silicon and sulphur contents observed in the coins is not surprising.

The other elements of interest are carbon, phosphorus and manganese. Carbon is reduced from the charcoal or coal (coke), and higher furnace temperatures along with more strongly reducing conditions are expected to yield a higher carbon content in the iron product if no other variables are considered. However higher furnace temperatures reduce more silicon and phosphorus into the iron, and these lower the carbon content of the liquid iron. In line with this, the coins with higher silicon and phosphorus contents were found in general to have slightly lower carbon contents than the low silicon-phosphorus coins. Phosphorus in cast iron normally originates in the iron ore, where phosphorus-bearing minerals are present along with the iron-bearing minerals. During smelting, the phosphorus dissolves in both the metallic iron and the silicate smelting slag but in general most of the phosphorus is expected to enter the metal. The variability of the phosphorus content in the coins presumably reflects some combination of higher furnace temperatures and the use of different iron ores, although slag conditions also affect the partition.

The higher furnace temperature would also be expected to reduce some manganese into the iron, provided that manganese is present in the ore, and hence the absence of detectable manganese in most of these coins suggests that low-manganese ores were smelted and/or that smelting temperatures were low. The iron in the one coin with a detectable manganese content, CM11, is likely to have been smelted from a different ore in comparison with the other coins; its silicon content was too low to be indicative of a high smelting temperature.

Another question which remains unanswered is whether the coins were cast into the coin moulds directly from a smelting (blast) furnace or from a remelting (e.g. cupola-type) furnace where iron, possibly iron that had originally been smelted in different furnaces and now in the form of pig iron and/or scrap, was melted together. Information obtained from these analyses does not shed light on this question. Although casting conditions can be better controlled from a remelting furnace, casting directly from a blast furnace has long been a common technique, for example most post-medieval European cast iron cannon were cast in this manner.[24] On the other hand, during Song times at least some iron used for coins was smelted elsewhere than at the mint sites, for example locally in payment of taxes, and delivered to the mint sites where it would necessarily have been remelted for casting into coins.[25]

Geographical and chronological differences
With the above thoughts in mind, it is of interest to consider the geographical origins of the Song coins analysed in this study. Mint locations are known for 23 of the 37 coins (**Table 4**). On the basis of the mint marks, 6 of the 23 coins were minted in modern-day Shaanxi province, north-central China, while the other 17 were minted in different mints: at Qichun (9 coins); Tong'an (6 coins); and Hanyang (2 coins). These three named mints were in the Song administrative departments of Qizhou, Shuzhou and Ezhou, respectively, and are located in modern-day Hubei and Anhui provinces, about 1,000 km to the southeast of Shaanxi (**Fig. 12**). These two different locations correspond with the two main areas where iron coins were circulated: Sichuan/Shaanxi and the Hubei/Anhui region, respectively.

Recent work relating to Song dynasty coins indicates that Qichun was close to modern-day Qichun, Hubei; Tong'an to modern-day Shucheng, Anhui; and Hanyang to modern-day Wuhan, Hubei. Combining historical texts and archaeological finds, Chen Hao writes that the Qichun mint opened in 1170, was expanded in 1185, and closed *c*. 1236–37.[26] Annual production reached 200,000 strings in 1185. The Hanyang mint opened *c*. 1190, and closed after 1232 (its annual production was reckoned together with the Fumin mint, at 200,000 strings in 1212). The Tong'an mint has recently been excavated, and among the finds were remains of poured iron as well as finished and unfinished iron coins of the Daguan (1107–10) and Zhenghe (1111–18) periods. This mint is known from historical records to have been casting iron coins during the period 1099–1214.[27] The Tong'an coins analysed here are all from the final 30 years of production.[28]

It is significant that in terms of composition and microstructure the Shaanxi coins are all similar to each other, being of the type which has high impurity levels and divorced eutectic microstructure, whereas all of the Hubei/Anhui coins are also similar to each other but of the other type, with low impurity contents and ledeburitic microstructures. This suggests that the three Hubei/Anhui mints were using the same or similar ore, the same or similar smelting conditions and that at least some of these parameters were different in the smelters that provided the Shaanxi mint. It is suggested that the difference between the Shaanxi coins and the Hubei/Anhui coins may well be related to the choice of smelting fuel in the different geographical locations, i.e. coal or coke in Shaanxi and charcoal in the Hubei/Anhui region. Coal deposits are

Table 4 Coins with mint marks

Coin	Reign period	Coin date	Si (wt%)	P (wt%)	S (wt%)	C (wt%)*	Microstructure
Shaanxi							
cm 12	Xuanhe	1119-1125	0.25	0.58	0.39	4.0	divorced eutectic
cm 13	Xuanhe	1119-1125	0.57	0.69	1.65	2.3	divorced eutectic
cm 17	Xuanhe	1119-1125	0.32	0.68	0.37	4.0	divorced eutectic
cm 14	Xuanhe	1119-1125	0.78	0.71	2.05	2.3	divorced eutectic
cm 15	Xuanhe	1119-1125	0.55	0.71	1.33	2.9	divorced eutectic
cm 16	Xuanhe	1119-1125	0.57	0.73	1.14	2.9	divorced eutectic
Qichun Inspectorate, Qizhou							
cm30	Chunxi	1174-1179	0.18	0.18	nd	4.3	ledeburitic
cm31	Chunxi	1188	nd	0.12	nd	4.3	ledeburitic
cm34	Shaoxi	1190	0.16	nd	nd	3.9	ledeburitic
cm35	Shaoxi	1191	nd	0.15	nd	4.2	ledeburitic
cm4	Jiading	1210	0.38	0.18	0.65	3.4	mixed
cm22	Jiading	1209	0.10	0.18	nd	4.8	ledeburitic
cm23	Jiading	1210	0.14	0.12	nd	4.5	ledeburitic
cm24	Jiading	1211	0.13	0.16	nd	4.8	ledeburitic
cm25	Jiading	1215	0.13	nd	nd	3.9	ledeburitic
Tong'an Inspectorate, Shuzhou							
cm33	Chunxi	1174-1179	nd	0.14	nd	4.9	ledeburitic
cm32	Chunxi	1185	nd	nd	nd	4.0	ledeburitic
cm36	Shaoxi	1191	0.16	0.10	nd	4.0	ledeburitic
cm37	Shaoxi	1194	nd	nd	nd	4.3	ledeburitic
cm26	Jiading	1209	nd	nd	nd	4.3	ledeburitic
cm27	Jiading	1210	nd	nd	nd	4.3	ledeburitic
Hanyang Inspectorate							
cm28	Jiading	1208	nd	0.22	nd	4.5	ledeburitic
cm29	Jiading	1209	nd	0.16	nd	3.6	ledeburitic
Dot in Crescent							
cm2	Chunxi	1174-1179	0.25	1.48	1.97	2.6	divorced eutectic
cm19	Chunxi	1174-1179	0.36	1.36	1.35	3.7	divorced eutectic

Notes: nd = not detected; * = estimated, as described in text

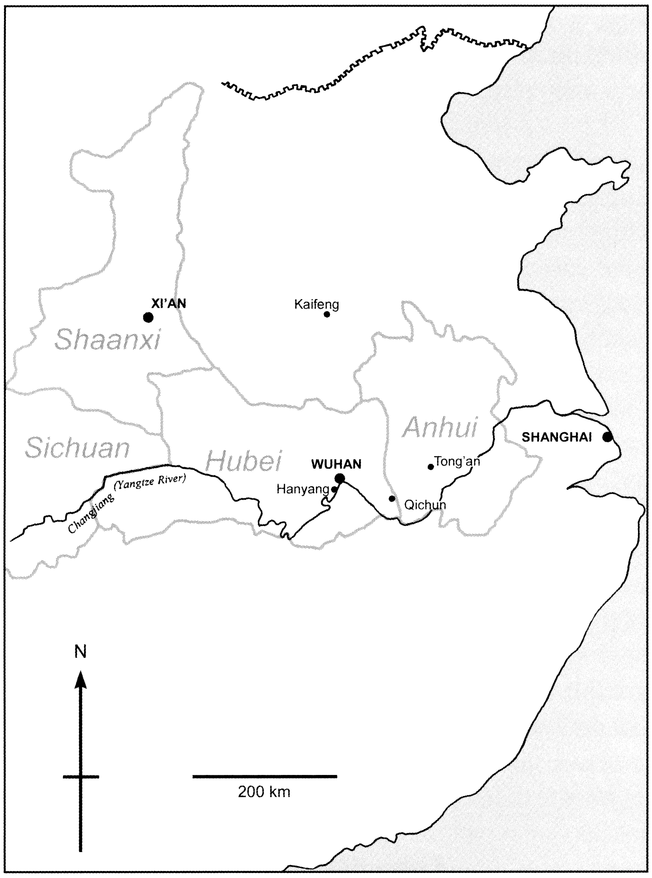

Figure 12 Map of central China showing the locations of the mints discussed, with names of present-day cities in upper case.

concentrated in the more northerly regions of China, including Shaanxi and in Sichuan, and it is known that coal production underwent explosive growth during the Song dynasty, stimulated by a shortage of wood on the north China plain.[29] On the other hand the south was much more heavily wooded, and the easy availability of wood meant that charcoal was greatly preferred as a fuel there. It is of interest to note that during the Northern Song period, serious shortages of charcoal in Kaifeng, the Song capital, necessitated the import of charcoal from the south, and a gradual change to coal or coke as a domestic fuel.[30] These considerations are fully consistent with the suggestion that the iron used for the Shaanxi coins was smelted with coke and that for the Hubei/Anhui coins with charcoal.

If the coins are considered strictly chronologically, all of the earlier (AD 1078–1125) ones have higher impurity contents and divorced eutectic microstructures, whereas the later (1174–1215) coins, other than those minted during the Chunxi reign period (1174–89), were of the low impurity, ledeburitic type. Of the nine analysed Chunxi period coins, five were in the earlier group and four in the later group. However, of the coins for which mint locations are known, all of the Shaanxi coins are early whereas all of the Hubei/Anhui coins are late, hence it is not possible to separate the effects of geographical location from those of chronology. Furthermore, it must be noted that the time interval between the earlier and later coins is relatively short, a matter of some 50 years. In view of the number of coins analysed here, it does not seem reasonable to draw firm conclusions with respect to the changes over time.

In summary, it can be said that there are great similarities among the coins minted within each of the two geographic regions, but very significant differences between the coins from the two regions. The sulphur contents of the Hubei/Anhui coins are so low as to suggest strongly that they are made of charcoal-smelted iron. The Shaanxi coins have undoubtedly been smelted from a different ore, but their higher silicon contents suggest higher smelting temperatures, and this in combination with the observed higher sulphur levels suggest strongly that they are likely to have been made of coke-smelted iron.

Coin production and processing

Examination of the microstructures revealed that all of the coins were in the as-cast condition, with no indications that following the casting operations the coins had been subjected to any thermal processing. This is as expected; there is no obvious reason why such heat treatment would be desirable. In the mid-1st millennium BC, Chinese ironworkers learned to heat treat white cast iron in order to decompose the cementite and then precipitate it as agglomerations of graphite, making malleable cast iron,[31] a process that much improved the toughness of the material (this malleablizing heat treatment did not appear in Europe until the late 17th century AD). Alternatively the heat treatment could remove the carbon from the cast iron without the precipitation of graphite, transforming it into a form of wrought iron or, in some cases, steel. Both of these heat treatments would have degraded the service performance of the coins, and it is not surprising that they were not used.

Some of the coins examined here showed evidence of the casting process by which they were produced, in the form of stubs projecting from the outer rim. These are vestiges of the gating system (sprues and ingates), the channels through which molten iron flowed in to fill the moulds. Because white cast iron is so hard and resistant to deformation, removal of these projections would have been very difficult to accomplish; filing or sawing would not have been possible for example. The hardness and strength of the white cast iron would also have precluded mechanical working, for example by forging or stamping, and, not surprisingly, no evidence of mechanical working was visible in the microstructures of the coins.

Since the coins were produced in large numbers[32] they would certainly have been cast using a high volume production process. It is likely that they were cast in 'trees', complex moulds in which many coins could be cast simultaneously from a central gating system, creating a solid array of branches (the frozen ingates) with a cast coin at the end of each branch.[33] This type of production technique would have been necessary to produce coins at the high rates and volumes required. Bronze coins were often cast directly in bronze moulds, many of which have been found. The moulds for the iron coins could also have been made of metal (permanent moulds) which would likely have survived hundreds of refillings before degrading to the point where they would have had to be replaced.[34] As an alternative to metal moulds, tree-type clay or sand moulds could have been utilized. Burger describes the process used for bronze coins. This process starts with 'mother' coins that served as patterns, and involves pressing the mother coins into a mould material such as a mixture of earth (loam) and coal to produce a mould, assembling a number of moulds into a stack and then pouring the casting. Here the mould would be destroyed with each casting, and mould production would be a major part of the casting operation. That the Chinese used this technique for casting bronze coins is well documented[35] and it is likely to have been used for iron coins as well. A related high volume stack moulding system was extensively used for production of iron castings for agricultural tools, hardware, etc.,[36] with both metal and clay moulds being employed. The recent report of the excavation of the Tong'an mint site did not mention mould material being found, but did mention pot sherds, porcelain sherds and broken brick from the Song period level.[37] After casting, clay coin moulds must be broken open to remove the cast coins, leaving only fragments that could have appeared similar to, and be mistaken for, pot sherds.

The coin microstructures, which have the potential to provide information about cooling rates of the liquid metal during and after freezing, were not revealing in this respect; none of the coins exhibited a chilled surface microstructure of the type which would be expected from rapid cooling. Rapid cooling is normally associated with metal moulds, which have good heat transfer and heat absorption capabilities. However rapid cooling can create problems when casting a small object like a coin, or especially an array of coins cast simultaneously. In these situations it is important to have enough metal flow to fill the mould(s) completely, avoiding premature freezing in the gating system which would block subsequent metal flow. In the case of white cast iron this is a particularly serious problem, more serious than for bronze coins, because the ingates must be relatively slender so that the coins can be readily broken off the 'trees' after solidification (the extreme hardness of white cast iron limits the possible techniques for this detachment). One way to use a metal mould with constricted ingates while avoiding their being blocked by premature freezing, would be to preheat it prior to casting in order to slow the cooling rate. With such preheating, a chilled surface on the coins would not have been expected even if metal moulds had been used. Furthermore, the temperature of the liquid iron prior to casting plays a role in determining cooling rate independently of mould material. Hence it is not surprising that the microstructure of the coin was unable to help determine the material from which the moulds had been made.

Conclusions

All the 37 coins analysed were found to have been made of white cast iron. Based on their compositions, the coins fell into two groups, one with relatively high levels of silicon, phosphorus and sulphur and relatively low carbon contents and the other with relatively low levels of silicon, phosphorus and sulphur and higher carbon contents. These compositional groupings are fully consistent with their microstructures which also fell into two groups, divorced eutectic microstructures in the high impurity low carbon irons, and ledeburitic microstructures in the low impurity high carbon irons. Two coins are intermediate between these two groups, both in composition and in microstructure. The fact that all of the coins are white cast irons is fully consistent with their compositions as they have relatively low silicon contents and many have relatively high levels of sulphur.

Of the 23 coins whose geographical origins are known from mint marks, two general minting areas are represented. Coins minted in Shaanxi were found to be all similar and of the divorced eutectic type. These are quite different from the coins minted in Hubei and Anhui, about 1,000km to the southeast, which are again similar to each other but different from the Shaanxi coins, being of the ledeburitic type. Although it is not possible to be certain, the cast iron from the Hubei/Anhui region is likely to have been smelted in charcoal-fired blast furnaces, while the iron in the Shaanxi coins is likely to have come from coke-fired blast furnaces. The coins were found to be in the as-cast condition, with no evidence of subsequent heat treating or working.

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cm12 cm13 cm17 cm14 cm15 cm16

cm18 cm2 cm3 cm19 cm20

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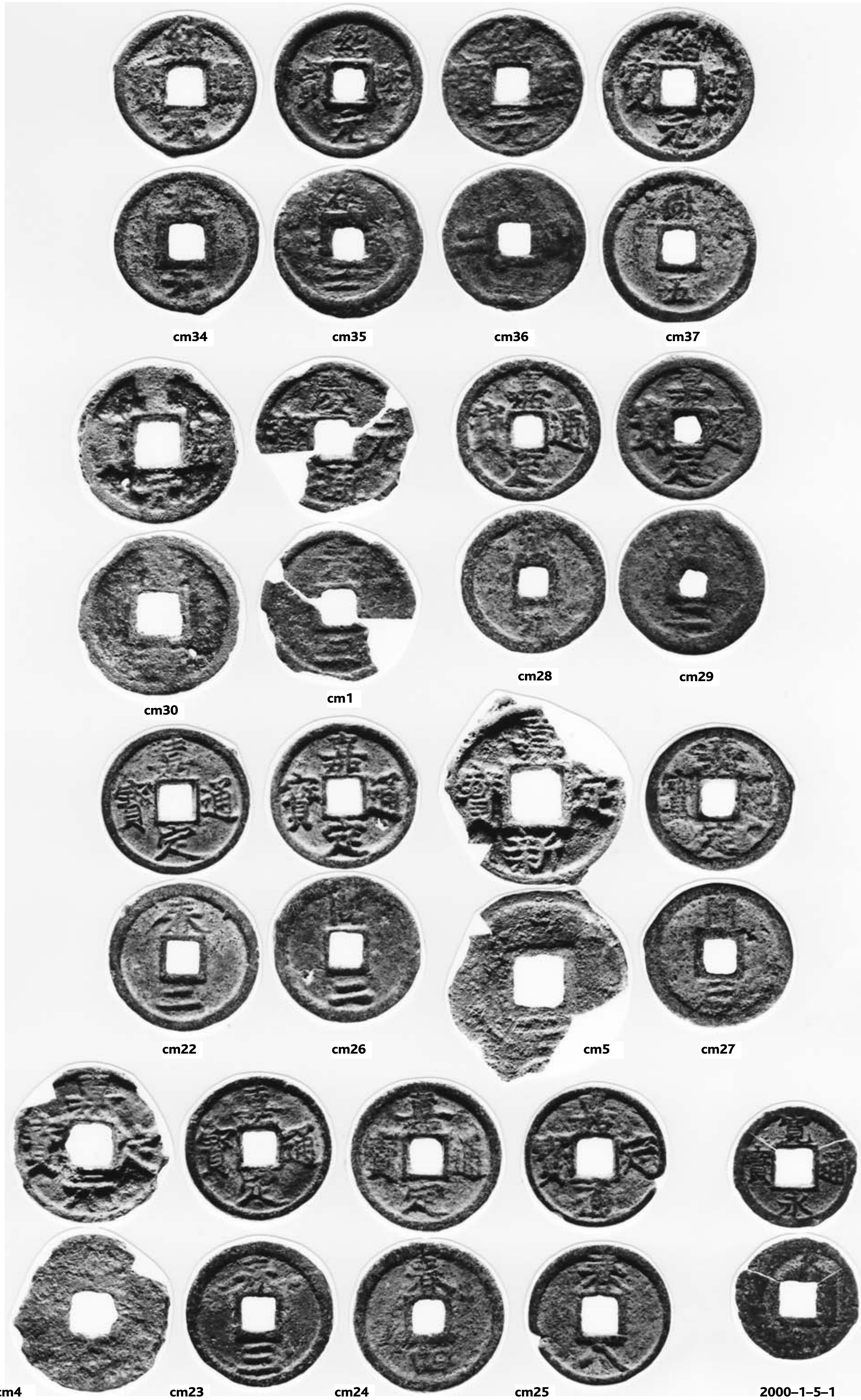
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Metal Supply for the Metropolitan Coinage of the Kangxi Period (1662–1721)

Michael Cowell and Helen Wang

In common with many coin series, the Chinese copper-alloy cash has not escaped the attention of the scientist. The chemical composition of coins within a series can provide useful technological information on metal production and supply over time. As the cash coinage was produced over 2,000 years, by a very consistent technology, it can provide an extensive database for this purpose, indicating the typical metal stocks and alloys available for manufacturing other Chinese copper-based, particularly cast, metalwork. Two groups have conducted analytical surveys of the series, which yielded very similar results, although different analytical techniques were used.[1] They showed that the coinage was essentially made of leaded tin bronze until the 16th century when there was a complete change to brass.

The first brass (or zinc-containing) coins occur as a minority within the otherwise bronze issues during the later Hongzhi period (1503–05)[2] but from Jiajing (1527–69) most of the coins were made of brass,[3] the officially prescribed alloy.[4] Initially, until the mid-17th century, the brass is not a simple copper-zinc alloy but contains substantial amounts of lead and some tin. Some of this may have been introduced in the form of scrap bronze although the amounts of lead and tin were sometimes officially prescribed[5] and were therefore presumably added as individual metals. There has been some debate[6] about how the brass was manufactured, either by the cementation (calamine) process or by speltering, adding metallic zinc to copper.[7] This is an interesting aspect as it may indicate when metallic zinc production commenced in China. The 17th-century Chinese technological treatise, *Tian gong kai wu* of 1637,[8] clearly refers to metallic zinc and its manufacture. On the basis of an entry in the *Ming Shi* which may indicate the addition of metallic zinc, Cowell *et al.* have suggested that speltering was used for the earliest 16th-century coin issues containing zinc,[9] and supported this with analytical evidence. Zhou Weirong and Fan Xiangxi[10] dispute this however, maintaining that the item refers only to the addition of tin. The high zinc content of the coins, coupled with relatively high amounts of lead and tin, clearly indicate that during the Wanli period (1576–1621) at the latest, the brass was made by speltering.[11] There is also a report of a zinc slab ingot with an inscription dating it to 1585 from Lianzhou, Guangdong province.[12] Evidence for earlier manufacture remains uncertain.

Cowell *et al.* had noted temporal variations in the trace element composition of the brass coins which were thought to be related to the metal source or production processes.[13] For example, there was a sudden, and sustained, increase in the amount of cadmium (a metal associated with zinc) in the coins dating from 1621 onwards which, it was thought, may have been caused by a change in the method of zinc production or the source of its ores.[14] Somewhat later than this, during the Kangxi period (1662–1721), there were systematic changes in a number of other trace elements, especially nickel, antimony, arsenic and cobalt which generally decreased in concentration and remained low until the later Qianlong period (1735–95).[15] It was suggested that this was the result of an influx of imported copper from Japan which was thought to have occurred at this time; the purpose of this note is to examine this connection in more detail through the presentation of new analytical data on Japanese ingots and contemporary Chinese coins.

From 1646 copper became a regular import from Japan, stimulated in the 1650s by European and, later, Chinese demand for the metal. The key traders of Japanese copper were the Dutch and Chinese, and most of the metal remained in the east: until 1666 the bulk was taken first to Taiwan[16] for redistribution, thereafter to Malacca. The steep rise in the price of Japanese copper in the 1660s was based on increasing Dutch demand and Japan's own domestic need for copper. After the 1660s Japanese production of copper expanded and could meet the demands of the Dutch and the Chinese.[17]

There was apparently free trade in Japan until 1672, when the Japanese introduced regulated trade. Free prices (previously determined by an auction system) were replaced by fixed prices, regulated by a joint Japanese-Dutch-Chinese council. The regulated trade continued until 1685 when prices were free again. Apart from a short interruption 1698–99, the volume of trade was fixed: the Dutch were allowed to sell goods up to a limit of 300,000 Japanese taels of silver, and the Chinese up to a limit of 600,000 taels of silver. In 1715 a system of regulation was re-introduced.[18] The copper trade was highly profitable, estimated at one point to account for 80% of the Dutch East India Company (Verenigde Oostindische Compagnie, 'VOC' trade).[19] At first, the Dutch had a virtual monopoly; they exported from Japan not only copper bars (the cheapest form of refined copper), but also copper alloy coins – almost 27 million coins in 1665 and almost 24 million coins in 1666.[20]

Chinese competition in the copper trade developed primarily in the hands of private merchants. The new Qing government had inherited the Ming policy of absolute exclusion against the Japanese, however the Japanese Tokugawa government had been actively encouraging Chinese merchants since the early years of the 17th century. By 1657 the Dutch court in Batavia was irritated by the competition, and instructed the VOC factory in Japan to try to put obstacles in the way of the Chinese buying up copper, as Chinese merchants had in 1656 conveyed some 17,000–18,000 piculs of copper to Batavia.[21] The irritation was further compounded by the fact that this copper was sold on to private traders and carried on VOC ships to Coromandel, Surat and Persia, thus stinging Dutch business there as well.[22]

The Chinese needed copper for minting coins. In 1644 the Qing government had set up two mints in the capital: the Board of Revenue and Board of Works, with an annual copper consumption of 22,000–24,000 piculs. The procurement of the necessary copper was in the charge of the Interior Revenue Offices (*neidi shuiguan*) in Zhili, Shandong, Jiangsu, Jiangxi and Zhejiang provinces. These offices used government funds to purchase copper from private merchants. During the 1650s and 1660s both the central and provincial mints were very active, and by the 1670s there was a serious shortage of copper. The provincial mints were shut down, and in 1673 severe penalties were placed on the use of copper for domestic purposes. In 1675 the operation of the various Chinese mints was reorganised, with the aim of increasing production, and orders were issued to buy in scrap copper. On the grounds that Chinese sea power was initially in the control of anti-Manchu forces, such as Zheng Chenggong's fleets, Hall suggests that for the first 40 years of operation the Qing mints were probably forced to subsist on domestic copper.[23]

Competition from the Chinese was so strong that in 1683–84 the Dutch planned a major project: to buy up all the Japanese copper intended for export. A proposition was made to the Japanese government for taking over 50,000–60,000 piculs of copper at a suggested price, with a contract to be binding for three to four years. The Japanese refused.[24] By the late 1680s, the Chinese were exporting more copper bars, scrap copper and copper plate than the Dutch, and by 1684 the VOC gave permission to the Chinese merchants in Batavia and Bantam to trade with Japan, on the ground that they had in fact been carrying on this trade for many years already.[25]

The year 1684 was a turning point: China's sea frontiers officially opened, and the Kangxi emperor ordered the Amoy and Fujian authorities to load ships with silk and sugar for Japan. In the 1680s and 1690s large numbers of Chinese trading vessels entered Nagasaki,[26] and the sudden growth of trade resulted in a heavy loss of Japanese silver and copper coins. In 1685 the Japanese limited the volume of trade permitted with China to 600,000 taels of silver, and stopped all export of specie, silver and copper, specifying that only merchandise could be removed. However, refined copper, in bulk, was categorised as merchandise. In 1699 copper procurement in China became the responsibility of the Imperial Household Dept (*neiwu fu*), in order that the government might exercise greater control over copper. Hall notes that by this time, Chinese mints were exclusively using Japanese copper, and suggests this may have been the case soon after 1684.[27]

That the changes in the composition of the Chinese coins can be explained by contemporaneous imports of Japanese copper is given strong support by recent analyses of contemporary Japanese copper ingots[28] and comparisons with the cash coinage.

Cowell *et al*. analysed a number of coins by X-ray fluorescence (XRF) and atomic absorption spectrometry (AAS) from the period of interest.[29] These included 16 coins of the Kangxi reign which were categorised into three chronological groups ('early', 'middle', and 'late') according to the arrangement devised by Burger, based on historical sources, calligraphy and size.[30] There were also analyses of the immediately preceding issues of Shunzhi (1644–61) and the succeeding issues of Yongzheng (1723–35) and Qianlong (1736–95). The data are reproduced and summarised in Appendix 1. It can be seen that the 'early' issues differ from the other Kangxi issues in alloy as well as trace elements. Thus, they have lower zinc, and higher lead and tin, and most of the trace elements are higher. Furthermore, there is continuity with the preceeding and succeeding issues until the later period of Qianlong when the trace elements return to higher concentrations. The data for the alloying elements (Zn, Sn, Pb) and some of the trace elements (Sb, As, Ni) are summarised chronologically in **Figures 1 and 2**, respectively.

The date of the transition from 'early' to 'middle' Kangxi types may be deduced from the alloy composition, specifically the zinc content. As found by Harthill for Qianlong issues,[31] there is often good correspondence between the prescribed composition of the coins and their actual analyses, provided that allowances are made for losses in manufacture. In 1683/4, to economise on copper, due to the high price of that metal, the alloy of the coins was altered from 70% copper: 30% zinc to 60% copper: 40% zinc.[32] The higher zinc content corresponds closely with that observed for the 'middle' period and later coins after allowing for loss of zinc by evaporation during manufacture;[33] hence the 'middle' period coins were presumably issued from 1683/4. The changes in the trace element composition during the Kangxi period parallel those of the zinc and therefore also occur from 1683/4. This coincides with the resumption of trade with Japan as described above. During the Qianlong period, especially from Harthill's period G (from about 1781), the concentrations of Sb, As, Ni all increase and revert to levels typical of the period before 1683.

For comparison with the late 17th-century Chinese coins, the composition of relevant metal supplies is shown by contemporary Japanese ingots and coins and Chinese coins manufactured close to, and presumably using, local supplies of copper. Appendix 2 lists some analyses of mid-17th-century Japanese coins,[34] late 17th-century Japanese copper bar ingots[35] and previously unpublished data on cash coins from Yunnan, issued under Shunzhi in the period 1653–62.[36] The bar ingots were recovered from the Dutch vessel *Waddingsveen* which was wrecked in Table Bay, Cape Town in 1697. Although these similar ingots were en-route to Europe from Japan they are probably similar to the supplies sent to China. This small number of ingots cannot of course be taken to represent all the output of copper from Japan.

It can be seen from Appendix 2 that the Japanese copper, or copper alloys, in this period are generally characterised by relatively low levels of a number of trace elements, particularly antimony, arsenic and nickel, which corresponds closely with that of the Kangxi metropolitan mint coins after 1683 and up to the later years of Qianlong. The Chinese copper from Yunnan on the other hand has much higher levels of these elements, corresponding with the Kangxi issues before 1683 and the later issues of Qianlong. To conclude, changes in the coin compositions appear to follow the historical events and correspond closely with the available metal stocks thus supporting the view that the Chinese coinage over the period 1683 to 1781 may have been manufactured largely using copper from Japan.

A list of the coins and ingots analysed is given in Appendix 3.

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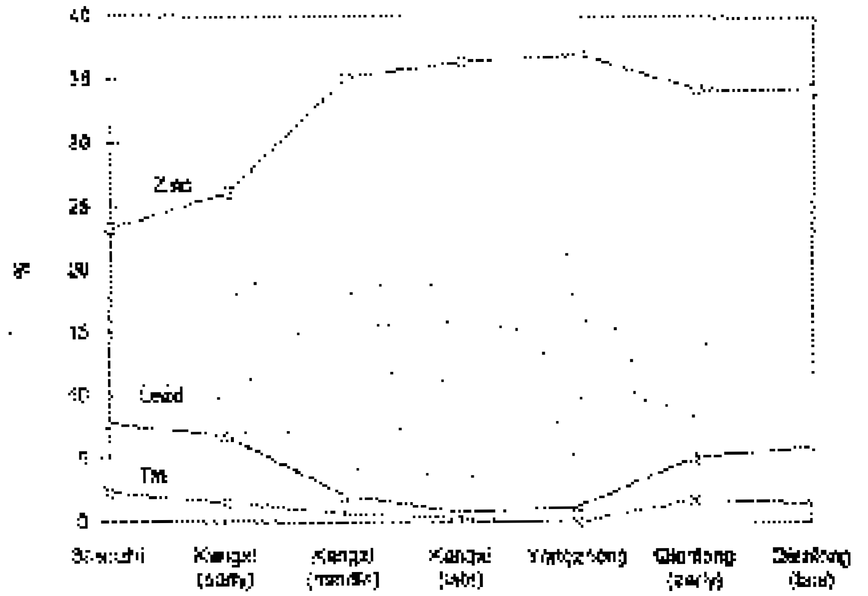

Figure 1 Mean concentrations of zinc, tin and lead in coin groups listed in Appendix 1

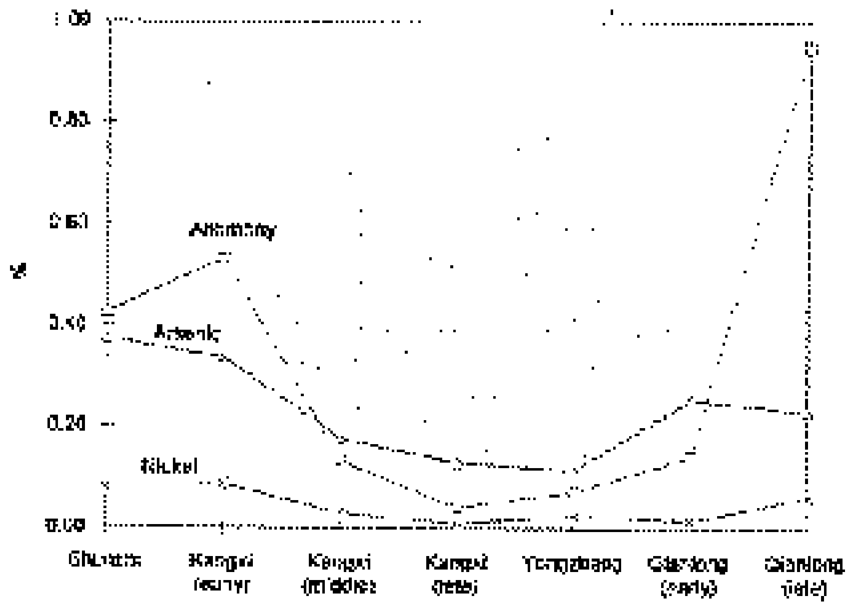

Figure 2 Mean concentrations of antimony, arsenic and nickel in coin groups listed in Appendix 1

Notes

1 S.G.E. Bowman, M.R. Cowell and J. Cribb, 'Two thousand years of coinage in China: an analytical survey', *Journal of the Historical Metallurgy Society* 23 (1989), 25–30; Zhao Kuanghua, Zhou Weirong, Guo Baozhang, Xue Jie and Liu Junqi, 'An analysis and discussion of the chemical composition of copper coins of the Ming dynasty', *Studies in the History of Natural Sciences* 7 (1988), 54–65 (in Chinese); Dai Zhiqiang and Zhou Weirong, 'Studies on the alloy composition of past dynasties copper coins in China', in T. Hackens and G. Moucharte (eds), *Proceedings of the 11th International Numismatic Congress* (Brussels, 1993), 311–24.

2 M.R. Cowell, J. Cribb, S.G.E. Bowman and Y. Shashoua, 'The Chinese cash: composition and production' in M.M. Archibald and M.R. Cowell (eds), *Metallurgy in Numismatics* 3 (1993), 185–98.

3 All the issues from this period and later, analysed by Cowell and Bowman (Cowell *et al.*, 'The Chinese cash' and Zhou Weirong (Dai Zhiqiang and Zhou Weirong, 'Studies'), contain substantial amounts of zinc.

4 There is evidence from the *Ming Huidian* that the official use of brass commenced in 1553, Zhou Weirong and Fan Xiangxi, 'A study of the development of brass for coinage in China', *Bulletin of the Metals Museum* (Japan Institute of Metals) 20 (1993), 35–45, however brass coins were used before this.

5 For example in the sixth year of Qianlong, D. Harthill, 'A study of the metropolitan coinage of Qian Long, *Numismatic Chronicle* 151 (1991), 67–120.

6 For example, Bowman *et al.*, 'Two thousand years'; Dai Zhiqiang and Zhou Weirong, 'Studies'; Zhou Weirong and Fan Xiangxi, 'A Study'.

7 For a description of the processes used for brass manufacture see P.T. Craddock, *Early Metal Mining and Production* (Edinburgh, 1995), 292–302.

8 See translation by E-Tu Zen Sun and Shion-Chuan Sun, *Chinese Technology in the 17th Century* (Pennsylvania Press, 1966), 165–69.

9 Cowell *et al.*, 'The Chinese cash'.

10 Zhou Weirong and Fan Xiangxi, 'Studies'.

11 It is generally recognised that the maximum zinc content which can be achieved in a brass produced by the cementation process is about 33%, assuming that the copper is finely granulated and contains no lead or tin. Any additional lead or tin, or subsequent alloying of the brass, will lower the maximum zinc content substantially and thus brass with more than 33% zinc must have been made by mixing metallic copper and zinc. See J. Day, *Bristol Brass: History of an Industry* (Newton Abbott, 1973) and M.B. Mitchiner, C. Mortimer and A.M. Pollard, 'The alloys of continental copper-base jetons (Nuremberg and medieval France excepted)', *Numismatic Chronicle* 148 (1988), 117–28.

12 The ingot, apparently one of many from this location, weighed 1 picul (133.3lb, about 60kg) and contained over 98% zinc with 'very small quantities of iron and lead'. See F. Browne, 'Early Chinese zinc', *Journal of the Royal Society of Arts* (correspondence) 54 (1916), 576.

13 Cowell *et al.*, 'The Chinese cash'.

14 This increased cadmium has been confirmed by other analyses, see Zhou Weirong, 'Application of zinc and cadmium for the dating and authentication of metal relics in ancient China', *Bulletin of the Metals Museum* 22 (1994), 16–21. However, the interpretation that this is concerned with the introduction of speltering, ie use of metallic zinc,

is unlikely to be correct as other evidence (such as high zinc contents) indicates the use of metallic zinc before 1621.

15 The increase coincides with Harthill's phase G for the Qianlong coinage, from about 1782, Harthill, 'A study'.

16 K. Glamann, 'The Dutch East India Company's trade in Japanese copper, 1645–1736', *Scandinavian Economic History Review* 1 (1953), 41–79, especially 52–54. Taiwan was the centre of the Dutch trade with China and Japan; the Dutch East India Company factory at Nagasaki came under the administration of the factory in Taiwan, the key Dutch channel to Chinese markets. From 1661 Taiwan was also the base for Zheng Chenggong (Koxinga), of the anti-Manchu resistance, and remained under his family until 1680 when it was incorporated into the Chinese empire.

17 Glamann, 'The Dutch East India Company's trade', 72.

18 Glamann, 47.

19 Glamann.

20 Glamann notes that these were used '… mainly in the Toncquin trade'; Glamann, 50–51.

21 If 1 picul = 59.7kg, then 17,000–18,000 piculs represent about 1,015–1,075 tonnes of copper. These early figures are not indicated in the Japanese table compiled by Atsushi Kobata, which implies that the first such exports by the Chinese took place in 1663; Atsushi Kobata, *Nihon dou kogyo shi no kenkyu* [Research on Japanese copper mines], (Tokyo, 1993).

22 Glamann, 76.

23 John Hall, 'Notes on the early Ch'ing copper trade with Japan', *Harvard Journal of Asiatic Studies* 12 (1949), 444–61, especially 451.

24 Glamann, 77.

25 Glamann, 75-78.

26 Hall, 'Notes', suggests over 100 Chinese ships entered Nagasaki.

27 Hall, 'Notes', 454.

28 P.T. Craddock and D.R. Hook, 'The British Museum collection of metal ingots from dated wrecks', in M. Redknap (ed.) *Artefacts from Wrecks* (Oxbow Monograph 84: Oxford, 1997), 143–54.

29 Cowell *et al.*, '*The Chinese cash*'.

30 W. Burger, *Ch'ing cash until 1735* (Taiwan, 1976).

31 Harthill, 'A study'.

32. Burger, *Ch'ing cash*, 67.

33 The losses were apparently as high as 25% relative (*Tian-gong kai-wu,* E-Tu Zen Sun and Shion-Chuan Sun, *Chinese Technology*) which would lead to a final concentration of about 33% zinc. However, judging by the composition of the coins the average zinc losses were probably nearer 15–20%.

34 Plasma spectrometry and neutron activation analyses by Y. Sano, K. Notsu and T. Tominaga, 'Studies on chemical composition of ancient coins by multivariate analysis', *Scientific Papers on Japanese Antiques and Art Crafts* 28 (1983), 44–58.

35 Inductively coupled plasma atomic emission spectrometry analyses by Craddock and Hook, 'The British Museum collection'.

36 Analyses by energy dispersive X-ray fluorescence (XRF) on polished areas on the edge of each coin. For details of the technique used see M. Cowell, 'Coin analysis by energy dispersive x-ray fluorescence', A. Oddy and M.R. Cowell (eds), *Metallurgy in Numismatics* 4, (Royal Numismatic Society, Special Publication no.30, London 1998), 448–60.

Appendix 1

Selected analyses of Shunzhi, Kangxi, Yongzheng and Qianlong metropolitan mint cash coins

The coins are all illustrated on Pls 1–3

Pl. no	Date	Cu	Zn	Sn	Pb	Fe	Sb	As	Ni	Ag	Co	Cd(ppm)	Mn	Bi	Technique	Cowell *et al.*
Shunzhi (coin dates as Berger, 1976, n. 31)																
1	1646-53	-	21.8	2.1	8.0	0.42	0.25	0.35	0.08	0.05	0.019	<10	<6	0.03	AAS	1
2	1646-53	-	24.6	3.1	7.5	0.54	0.21	0.45	0.08	0.05	0.018	<15	<9	0.05	AAS	2
3	1653-57	-	24.4	2.1	6.8	0.49	0.37	0.37	0.09	0.08	0.017	<14	<9	0.09	AAS	3
4	1653-57	-	26.5	1.6	6.2	0.55	0.66	0.40	0.08	0.05	0.20	<11	<7	0.05	AAS	4
5	1657-62	65	20.8	2.7	9.9	0.58	0.54	0.28	0.07	0.04	-	-	-	-	XRF	5
6	1657-62	-	21.1	2.6	8 4	0.50	0.52	0.39	0.08	0.05	0.013	<11	<6	0.05	AAS	6
Kangxi (early) (coin dates as Berger, 1976, n. 31)																
7	1662-83/4	-	21.8	1.8	7.2	0.54	0.88	0.40	0.10	0.06	0.018	<7	<4	0.05	AAS	42
8	1662-83/4	-	21.9	1.8	6.8	0.56	0.70	0.39	0.09	0.06	0.018	<10	<6	0.03	AAS	41
9	1662-83/4	61	29.8	1.2	6.7	0.87	0.27	<0.20	0.07	0.03	-	-	-	-	XRF	43
10	1662-83/4	61	30.4	1.3	6.4	0.88	0.28	0.22	<0.05	0.03	-	-	-	-	XRF	44
Kangxi (middle) (coin dates as Berger, 1976, n. 31)																
11	1684-1723	-	37.6	0.2	1.0	0.76	0.03	0.22	<0.01	0.01	0.007	16	27	<0.02	AAS	51
12	1684-1723	-	34.6	0.5	2.0	0.35	0.13	0.15	0.03	0.03	0.006	13	<6	<0.02	AAS	52
13	1684-1723	-	34.6	0.9	4.2	1.31	0.21	0.21	0.04	0.04	0.011	<18	32	0.08	AAS	49
14	1684-1723	63	35.6	<0.1	0.9	0.25	<0.05	<0.20	<0.05	<0.03	-	-	-	-	XRF	50
15	1684-1723		35.6	<0.1	1.3	0.47	0.06	0.17	0.02	0.03	0.009	29	17	0.005	AAS	45
16	1684-1723	65	33.9	<0.1	0.7	0.07	<0.05	<0.20	<0.05	<0.03	-	-	-	-	XRF	46
Kangxi (late) (coin dates as Berger, 1976, n. 31)																
17	1684-1723	66	33.1	<0.1	0.7	0.09	<0.05	<0.20	<0.05	<0.03	-	-	-	-	XRF	47
18	1684-1723	-	36.6	0.2	1.1	0.49	0.05	0.14	0.01	0.03	<0.008	14	27	0.04	AAS	48
19	1684-1723	-	35.1	0.2	0.6	1.60	<0.03	0.16	0.01	0.04	0.008	27	95	<0.03	AAS	53
20	1684-1723	-	36.8	<0.1	0.9	0.38	<0.02	0.13	<0.01	0.04	0.007	34	7	0.04	AAS	54
21	1684-1723	63	35.7	<0.1	0.7	0.33	<0.05	<0.20	<0.05	<0.03	-	-	-	-	XRF	55
22	1684-1723	-	41.1	<0 1	0.6	0.50	0.03	0.09	0.01	0.03	0.006	15	30	<0.02	AAS	56
Yongzheng																
23	1723-36	61	37.4	<0.1	1.5	0.31	0.08	<0.20	<0.05	<0.03	-	-	-	-	XRF	58
24	1723-36	-	37.8	<0.1	1.5	0.28	0.02	0.11	0.04	0.02	0.005	77	<5	0.03	AAS	57
25	1723-36	63	35.7	<0.1	1.1	0.29	0.12	<0.20	<0.05	<0.03	-	-	-	-	XRF	60
26	1723-36	-	36.9	<0.1	0.8	0.39	0.07	0.12	0.01	0.04	0.004	51	<4	<0.02	AAS	59
Qianlong (coin dates from Harthill, 1991, n. 6)																
27	1736-40	-	36.5	0.1	0.8	1.36	0.13	0.34	0.01	0.04	<0.005	340	95	<0.02	AAS	61
28	1736-40	-	39.2	<0.1	06	0.47	<0.02	0.09	0.01	0.03	0.006	283	6	<0.02	AAS	62
29	1742-45	-	29.6	3.0	6.6	0.40	0.09	0.17	0.01	0.01	-	-	-	-	XRF	63
30	1742-45	57	32.4	2.1	7.8	0.31	0.18	0.13	<0.05	0.40	-	-	-	-	XRF	64
31	1755-60	-	33.6	1.7	6.6	0.43	0.16	0.16	0.02	0.04	0.009	<16	<9	0.05	AAS	65
32	1755-60	-	34.0	1.7	7.5	0.51	0.11	0.51	0.02	0.04	<0.006	15	19	<0.02	AAS	66
33	1771-81	-	33.3	1.9	7.7	1.12	0.14	0.21	0.03	0.05	0.005	12	52	<0.02	AAS	70
34	1771-81	-	35.7	1.9	3.3	0.59	0.19	0.42	0.02	0.07	<0.006	10	11	<0.02	AAS	69
35	1782-95	59	32.1	1.9	4.5	1.20	1.00	0.21	0.05	0.02	-	-	-	-	XRF	68
36	1782-95	-	32.4	1.4	6.9	1.76	1.22	0.44	0.12	0.05	0.029	29	17	0.06	AAS	67
37	1782-95	54	35.7	1.5	5.7	1.60	0.90	0.20	0.05	0.03	-	-	-	-	XRF	71
38	1782-95	53	36.6	1.2	6.6	1.60	0.69	0.08	0.02	0.02	-	-	-	-	XRF	72

Precision and accuracy of X-ray fluorescence (XRF) and atomic absorption (AAS) analyses.
AAS, 1-2% for major elements (Zn, Sn, Pb), 5-20% for remainder depending on concentration.
XRF, 2-5% for major elements (Zn, Sn, Pb), 10-25% for remainder depending on concentration.

Appendix 2

Analyses of 17th-century Japanese and Chinese metalwork

The ingots and Chinese coins are illustrated on Pl. 4.

Japanese coins (Sano, Notsu & Tominaga, 1983, n. 35)

Coin	Date	Cu	Zn	Sn	Pb	Fe	Sb	As	Ni	Ag	Co	Mn(ppm)	Bi
SN&T 44	1636	67.2	0.08	6.3	25.8	0.11	0.06	0.11	0.001	0.180	0.018	< 10	-
SN&T 45	1668	69.4	0.08	7.1	22.9	0.03	0.05	0.18	0.010	0.037	0.002	< 10	-

Japanese ingots (Craddock & Hook, 1997, n. 29)

Coin	Date	Cu	Zn	Sn	Pb	Fe	Sb	As	Ni	Ag	Co	Mn(ppm)	Bi
44	1697	99.9	<0.01	<0.01	1.06	0.024	0.02	0.04	0.02	0.021	0.003	-	<0.015
45	1697	97.4	<0.01	<0.01	1.10	0.006	0.02	0.04	0.02	0.021	0.003	-	<0.015
46	1697	98.2	<0.01	<0.01	0.49	0.006	<0.01	0.02	0.06	0.013	0.002	-	<0.015
47	1697	98.3	<0.01	<0.01	1.01	0.006	0.02	0.05	0.02	0.020	0.007	-	<0.015
48	1697	96.7	<0.01	<0.01	1.51	0.006	<0.01	0.02	0.03	0.020	0.011	-	<0.015
49	1697	99.2	<0.01	<0.01	0.64	0.006	<0.01	<0.02	0.02	0.020	0.012	-	<0.015

Chinese coins: Shunzhi, Yunnan mint (numbers refer to Plate)

Coin	Date	Cu	Zn	Sn	Pb	Fe	Sb	As	Ni	Ag	Co	Mn(ppm)	Bi
39	1653-62	84	10.0	0.4	3.6	0.60	0.80	0.40	0.13	<0.05	-	-	-
40	1653-62	84	10.2	0.3	3.6	0.50	0.80	0.60	0.10	0.06	-	-	-
41	1653-62	83	11.8	0.2	3.6	0.80	0.40	0.40	0.11	0.08	-	-	-
42	1653-62	83	11.1	0.3	3.9	0.51	0.70	0.40	0.10	<0.05	-	-	-
43	1653-62	81	12.5	0.4	4.1	0.50	0.60	0.50	0.07	<0.05	-	-	-

Appendix 3

List of the coins and ingots analysed

Pl. no.	Table no.	Board of Revenue mint	BM nos	Wt (g)
1	500	Shunzhi tongbao	1882-6-1-585	3.96
2	499	Shunzhi tongbao	1883-8-2-1652	4.24
3	498	Shunzhi tongbao	1882-6-1-600	3.86
4	497	Shunzhi tongbao	W97	4.13
5	502	Shunzhi tongbao	1882-6-1-624	4.21
6	501	Shunzhi tongbao	1882-6-1-622	3.97
7	504	Kangxi tongbao	1975-9-29-39	4.95
8	503	Kangxi tongbao	1976-1-12-3	4.22
9	505	Kangxi tongbao	1975-4-29-55	3.31
10	506	Kangxi tongbao	1975-9-29-51	3.11
11	513	Kangxi tongbao	1975-9-29-118	4.45
12	514	Kangxi tongbao	GC 458	4.73
13	511	Kangxi tongbao	1975-4-29-112	2.79
14	512	Kangxi tongbao	1882-6-1-655	3.02
15	507	Kangxi tongbao	1975-9-29-91	3.01
16	508	Kangxi tongbao	1975-9-29-92	2.77
17	509	Kangxi tongbao	1883-8-2-1862	2.63
18	510	Kangxi tongbao	1902-6-8-137	2.80
19	515	Kangxi tongbao	1882-6-1-731	4.89
20	516	Kangxi tongbao	1882-6-1-730	5.01
21	517	Kangxi tongbao	1975-9-29-96	3.54
22	518	Kangxi tongbao	M339	4.61
23	525	Yongzheng tongbao	M388	4.14
24	524	Yongzheng tongbao	1870-5-7-14846	5.09
25	527	Yongzheng tongbao	1883-8-2-1911	4.08
26	526	Yongzheng tongbao	M389	4.23
27	533	Qianlong tongbao	1882-6-1-759	4.13
28	534	Qianlong tongbao	1882-6-1-760	4.48
29	535	Qianlong tongbao	1870-5-7-14868	4.57
30	536	Qianlong tongbao	1882-6-1-763	3.96
31	537	Qianlong tongbao	1882-6-1-766	4.78
32	538	Qianlong tongbao	M417	4.92
33	542	Qianlong tongbao	1870-5-7-14871	4.54
34	541	Qianlong tongbao	1882-6-1-789	4.30
35	540	Qianlong tongbao	M415	3.89
36	539	Qianlong tongbao	1882-6-1-781	4.37
37	543	Qianlong tongbao	1882-6-1-771	4.24
38	544	Qianlong tongbao	1882-6-1-773	4.16

Yunnan mint

Pl. no.	Table no.	Yunnan mint	BM nos	Wt (g)
39	496	Shunzhi tongbao	1882-6-1-617	5.74
40	493	Shunzhi tongbao	1870-5-7-14785	4.09
41	492	Shunzhi tongbao	1886-10-6-664	4.27
42	494	Shunzhi tongbao	1882-6-1-616	3.89
43	495	Shunzhi tongbao	M324	4.21

Ingots of Japanese copper from the VOC vessel *Waddingsveen*

Pl. no.	Table no.		BM nos	Wt (g)
44	-	-	1995-1-2-1	58
45	-	-	1995-1-2-2	80
46	-	-	1995-1-2-3	113
47	-	-	1995-1-2-4	113
48	-	-	1995-1-2-5	120
49	-	-	1995-1-2-6	118

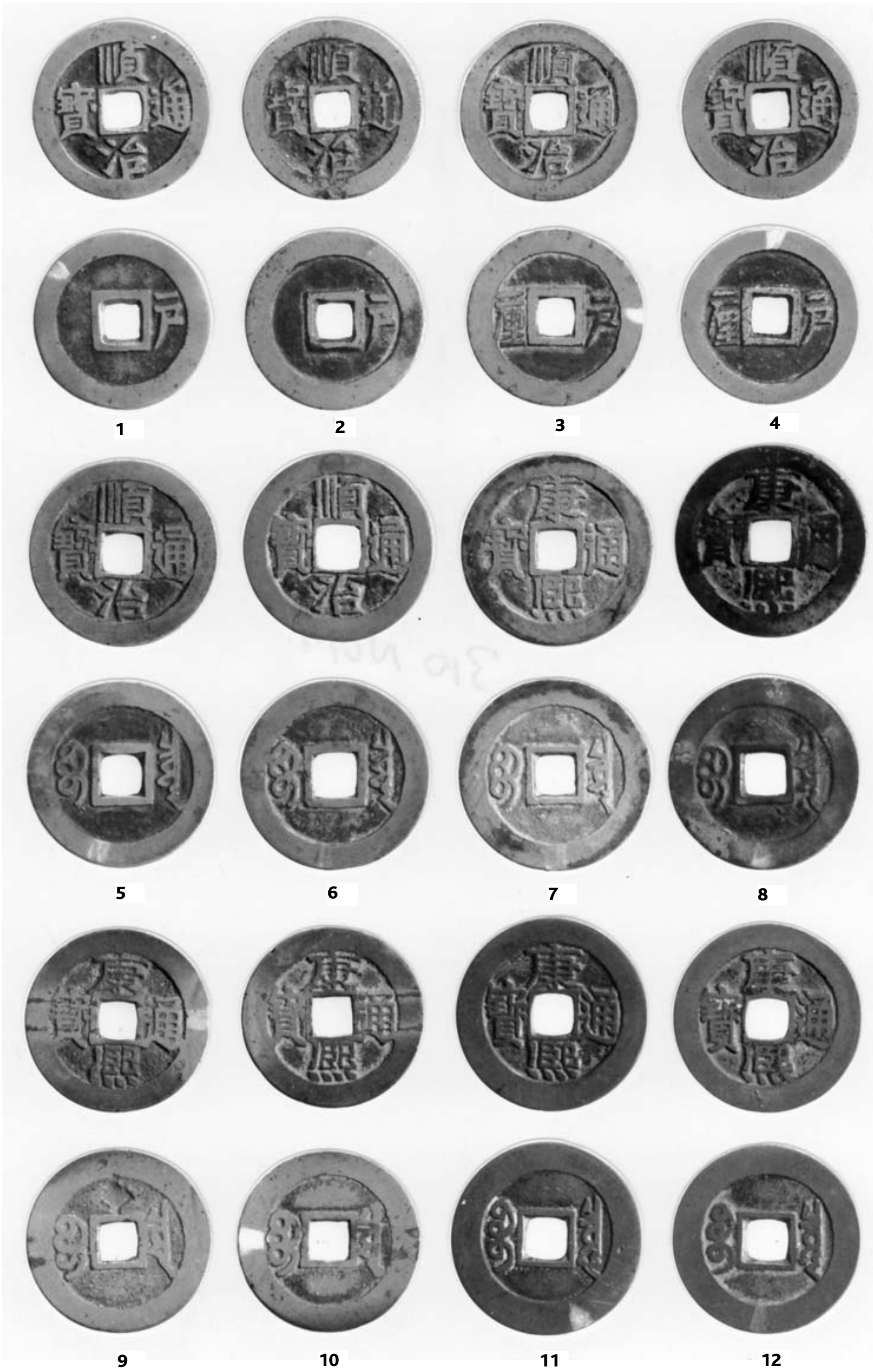

Plate 1

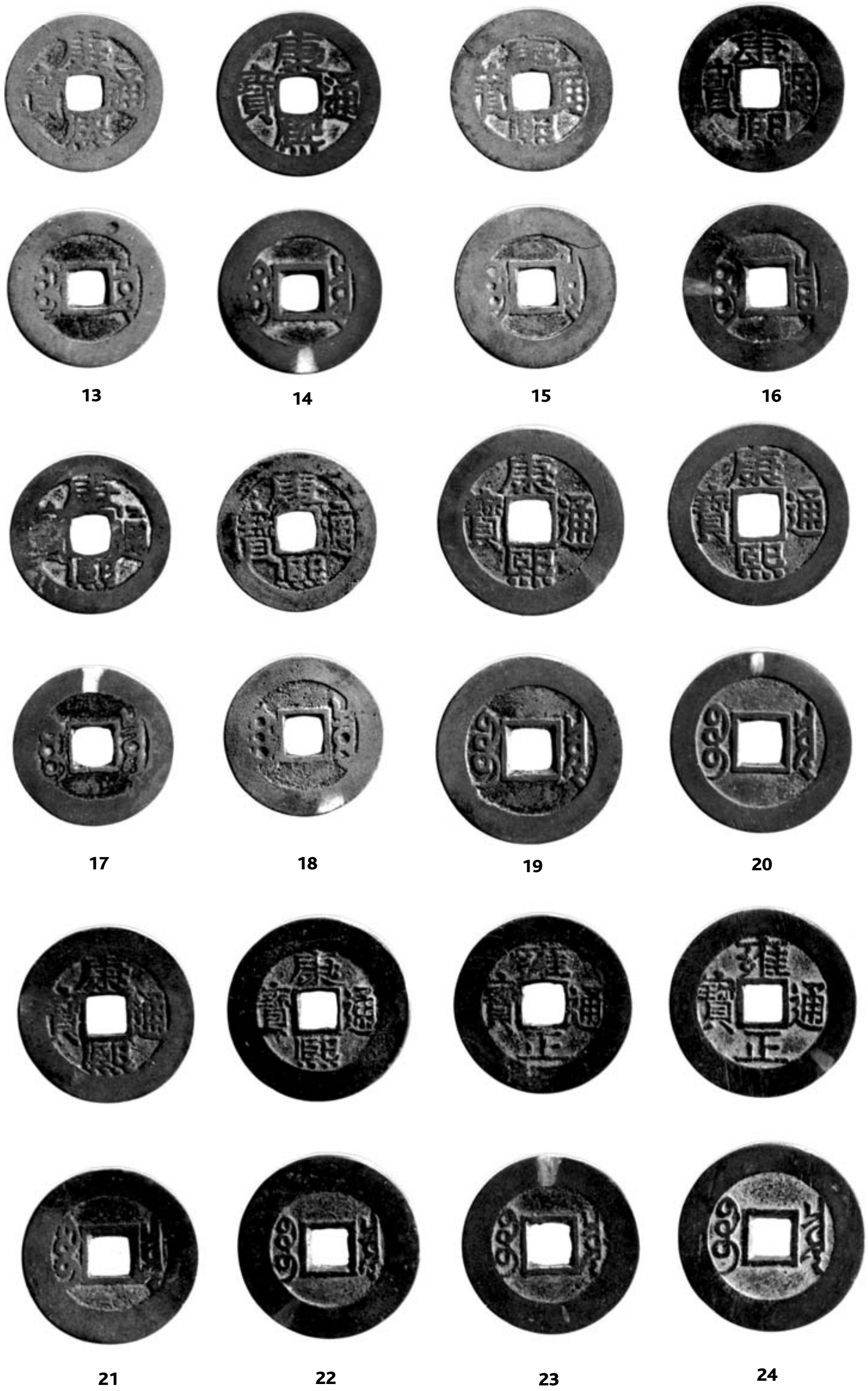

Plate 2

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Plate 3

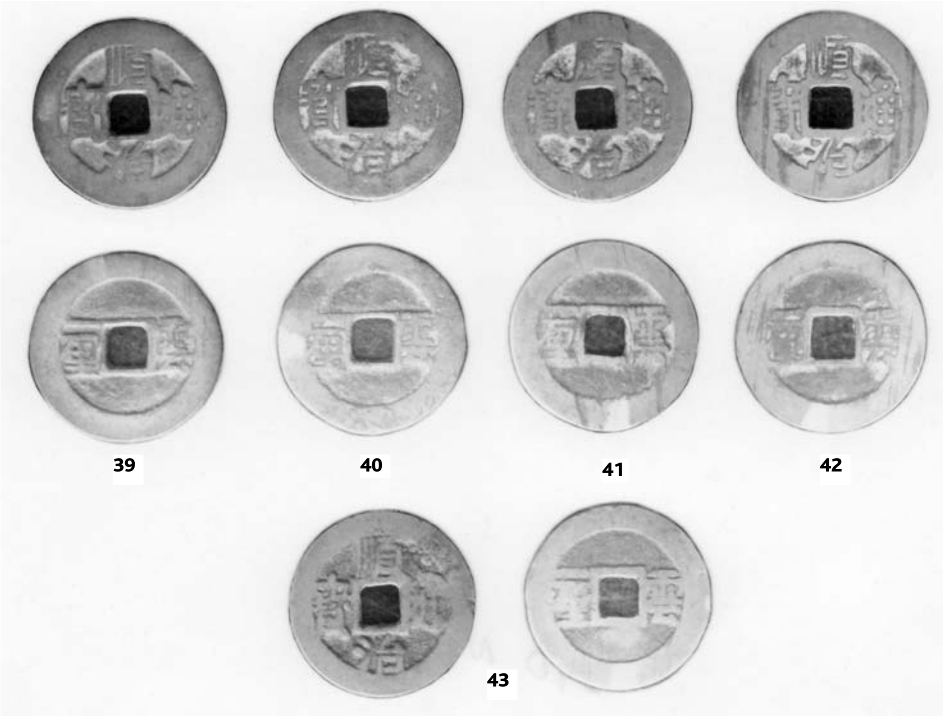

Plate 4

Appendix
Chinese Coins: Alloy Composition and Metallurgical Research

Chinese Coins: Alloy Composition and Metallurgical Research *is a new book by Zhou Weirong, published in Beijing (*Zhongguo gudai qianbi hejin chengfen yanjiu*, Beijing: Zhongghua shuju, 2004, ISBN 7-101-04089-6/H.195). It brings together the results of the metallurgical and numismatic research on Chinese coins undertaken by Zhou Weirong since 1985. In the largest metallurgical project on coins ever undertaken in China, he applied classical methods of chemical analysis (wet method) to over 2,000 Chinese coins from the 6th century BC to the early 20th century. The book presents the metallurgical data and illustrations of the specimens tested, and, most importantly, interprets the results by drawing together the metallurgical data, numismatic and textual evidence of the coins. In so doing, Zhou has tracked the development of the alloy composition in Chinese coin production, thereby showing the composition of Chinese coins through the ages, and also providing a unique survey of the evolution of metal alloys in China. He has also made a comprehensive investigation of the use of the minor elements in the alloys, such as iron, zinc, cobalt, nickel, cadmium, silver, gold, arsenic and antimony. The Introduction, Postscript and Contents of the book have been translated into English by Helen Wang, with the permission and approval of Zhou Weirong.*

Introduction by Zhou Weirong

Chinese coinage

Chinese coinage represents the eastern tradition of coinage, and is an important and influential branch of world coinage. There are two major characteristics of this tradition: first, that from their very beginning down to the late 19th century, Chinese coins were cast in moulds. Second, that bronze coins were the main form of currency. These two characteristics mark the eastern tradition of coinage as being very different from that of the west, where coins were typically struck with dies, and made of gold, silver and bronze.

Archaeologists have confirmed that bronze money was being cast in China as early as 600 BC. The bronze-casting site at Houma, Shanxi province, has yielded early hollow handle spades, moulds for making such spades, and bronze remains of the casting process. Other sites with early coin casting remains include Yan Xiadu (the lower capital of the Yan state) and sites of the Zhongshan state, all in Hebei province; the ancient city of the Qi state at Linzao in Shandong province; and the Zhenghan city site at Xinzheng in Henan province. However, the overall picture suggests that coinage in the pre-Qin period was not well controlled; the coins of the various states were different in form and manufacture, and the quantity of coinage was probably also rather small.

The unification of the various Warring States to form the Qin dynasty led to the unification of currency. With the rapid social and economic progress of the Han dynasty, Chinese coinage entered its first stage of major development. According to historical records, between 114 BC– *c.* AD 1–5, a period of almost 120 years, the total number of coins cast officially by the Han court reached over 28,000,000,000. Furthermore, lead and iron coins have been unearthed in some parts of China, suggesting that these were produced in regions where bronze coins were in short supply. During the Wei, Jin and Northern and Southern Dynasties, great social upheaval and economic downturn rendered production and circulation of coinage very difficult.

The Tang dynasty brought a new social stability and a flourishing economy, and Chinese coinage entered its second major stage of development. The earlier coinage based on the *liang* and the *zhu* weights which had been in circulation for over 800 years was replaced with the new *tongbao* system. Records show that during the prosperous reign of the Tang emperor Xuanzong 'the ninety-nine furnaces under heaven' produced an annual output of 327 million coins.

Chinese coinage entered its third stage of major development during the Song dynasty, a period of great economic prosperity. The Song dynasty was a golden age of coin-casting, in terms of the enormous quantity of coins produced, their variety, the precision of the alloy composition, and the great technical skills employed. The *Songshi* [History of the Song dynasty] states that during the reign of the emperor Shengzong over 5,000 million bronze coins and over 880 million iron coins were produced.

The rise of paper money after the Song dynasty led to an overall decline in coin production, although the technical side remained of a high standard. In the late Qing dynasty, coin-minting machinery was imported from the west, and the traditional Chinese cast coin was eventually replaced by the machine-struck copper dollar.

Numismatics in China

The study of ancient coins began as early as the 5th century in China, and by the mid-6th century, the first two numismatic books had been written: Liu Qian's *Qian zhi* and Gu Huan's *Qian pu*. Unfortunately, neither has survived in its original form, but only in the records of later numismatists. The Tang dynasty scholar Feng Yan compiled the *Xu qian pu* [An expansion of the *Qian pu*]. This contains the earliest record of the discovery and excavation of Eastern Zhou coinage (770–256 BC), along with some of the first attempts at their identification.

During the Song dynasty, the increased attention to excavated antiquities also stimulated an interest in coins among scholars such as Dong You, Hong Zun, Zheng Qiao and Luo Bi. The scripts on ancient coins were difficult to read, there were few books which they could consult, and this, combined with the Song fashion for myths and legends, gave rise to the creation of a number of fanciful appellations, relating to myths of early China: for example, *Huangdi huo* 'money of the Yellow

Emperor', and *Shen Nong quan* 'coins of Shen Nong'. In the absence of scientific investigation, these terms persisted.

The great advance in numismatics came with the move to more factually based research in the Qing dynasty, especially from the Qianlong reign (1736–95) onwards. Books such as Chu Shangling's *Ji jin suo jian lu* [*Record of bronzes I have seen*] (1819) and Li Zuoxian's *Gu quan hui* [*Collection of ancient coins*] (1864), show a more serious and scholarly attitude towards the identification of ancient coins. They remain important reference works to this day, and are seen as the classics of traditional Chinese numismatics. In 1938, Ding Fubao published his epic work *Gu qian dacidian* [*Encyclopaedia of ancient coins*], in which he brought together the results of traditional Chinese numismatics. In 1940 the *Quanbi xueshe* [China Coin Society] was established in Shanghai, with its regular journal, *Quanbi* [*Coins*].

Although there was a substantial amount of research on Chinese coins between the 5th century and the first half of the 20th century, the focus was very clearly on collecting, and books on numismatics were largely written by and for collectors. Little, if any, attention, was paid to the information inherent in the coins themselves. For this reason, it is true to say that for the first 1,500 years, the study of Chinese coins did not break free from the bonds of the very traditional field of Chinese epigraphy, known as *jinshixue* 'the study of inscriptions on metal and stone'.

From the 1950s, however, scientific archaeology breathed new life into the subject. Not only did it provide a large quantity of reliable evidence from excavations, it also opened the eyes of the coin specialist to the fact that archaeological data attached to the coins could help solve difficult questions. From this point on, numismatics developed largely on the back of archaeology.

The late 1970s and early 1980s saw a renaissance of academic research in China, and an unprecedented development in numismatics. The China Numismatic Society was established in 1982, and its quarterly periodical *Zhongguo Qianbi/China Numismatics* was established in 1983. There are now over 30 numismatic journals in China and well over 100 specialist illustrated books devoted to Chinese numismatics. This rapid development in the subject is due to two factors: first, the results of field archaeology. Since the 1980s archaeological fieldwork, planned or preliminary to construction work, has brought a vast amount of information to the field. To date, about 100 coin-casting sites have been discovered, and millions of coins have been excavated. Second, the application of science and technology since the 1980s has, quite simply, revolutionised the field of Chinese numismatics.

Metallurgical studies of Chinese coins

The first metallurgical studies of Chinese coins were undertaken over 100 years ago by Dr Koga Yoshimasa of the Osaka Mint, who, in 1910 analysed 113 East Asian coins, of which 59 were Chinese.[1] By means of investigating the alloy composition of ancient coins he sought to establish a body of data to which he could refer when preparing the production of modern coins. A scientist rather than a numismatist, he opened up the way for metallurgical study of ancient coins.

In the early 1920s, the scientists Zhang Hongzhao and Wang Jin investigated the alloy composition of Chinese coins from the perspective of the history of metallurgy, and achieved some notable results. Taking the zinc content of coins of Wang Mang's reign and of the Song dynasty as a basis, Zhang Hongzhao then developed his views on the history of zinc in China, which in turn became a focal point in the metallurgical world.[2] Wang Jin was one of the first scholars to propose that the metal content of Chinese coins could be investigated and that the results could be applied to historical questions. Indeed, his article on *wuzhu* coins became a model example showing how metallurgical analysis could be combined with textual evidence as a means of examining historical questions.[3] His discussion on the relationship between solder, lead and tin, and his explanation of the changes in the zinc content in coins are still valid. At the same time, Masumi Chikashige was making important headway as he studied the metal content of ancient coins as a means of investigating China's early coinage.

In the late 1920s and early 1930s, the Japanese scholars Kato Shigeshi and Dono Tsurumatsu took metallurgy in numismatics further, by means of their chemical analysis and metallographic study of the coins.[4] However, there are limitations to the data they collected, and some of their points and conclusions still require further attention.[5] The Chinese scholars Wu Chengluo and Shen Xiongqing were also engaging in similar work at that time.[6]

Between the 1940s and 1960s there was very little development. There was only occasional publication of any data, with the exception of two articles by Wang Jin, in which he applied the knowledge of the alloy composition of Chinese coins to the history of metallurgy in China.[7]

The 1970s saw developments in scientific instruments and apparatus, and in non-destructive methods and methods requiring smaller samples, such as EPMA, SEM, XRF, AAS and NAA, were used to analyse the metal content of coins. This opened the way for further work on the alloy composition of coins, and in the 1970s and 1980s the international worlds of archaeometry and history of science and technology published a large amount of data relating to the metal alloys used to make coins. Several hundreds of Chinese coins were tested, in particular by Japanese specialists working on antiquities and archaeology.[8] Hower, the value of these results for further research was limited. Chinese coins were cast, using Cu-Pb-Sn or Cu-Pb (sometimes Cu-Sn) alloys, the composition of which was not always consistent, and many of the tests on Chinese coins did not yield precise or accurate enough results.

Before the 1980s, although scientific research had touched upon Chinese coins, only a small number of scientists had taken any interest in the results, and if the Chinese numismatic world noticed them at all, they had done nothing with them. The absence of mutual interest and co-operation meant that the scope and results of such analyses were limited. However, the situation changed drastically in the 1980s when Dai Zhiqiang, Zhao Kuanghua and Hua Jueming carried out more in-depth research on metal alloys.[9] This co-operation marked a watershed. In the numismatic world, no longer was it sufficient to consider Chinese coins in the traditional ways. The impact was also felt in the broader academic world. As a scientist, I turned my attention to the alloy composition of coins, and used the results to carry out the first systematic studies of zinc smelting and brass in China.[10] The results demonstrated the importance of bringing together the alloy composition of coins and the history of metallurgy. Those working in the diverse worlds of antiquities, museums, science and technology, archaeology, numismatics and history of metallurgy sat up and took notice. Metallurgical analysis of coins began to take off in various places, and much of the data was published. Indeed, statistics show that by the end of 1989, over 800 coins had been tested as part of official and unofficial projects around China. It is worth pointing out that the most common method used for testing the coin alloy was the chemical quantitative method, that the results were largely accurate and reliable, and that they provided a sound foundation for further research into the alloy composition of coins.

In the 1990s came another breakthrough, as scientists and numismatists co-operated on a large project examining the alloy composition of Chinese coins. Before testing, all the coins were identified and authenticated by numismatists. The scientists then carried out the tests. The coins were then re-examined with the benefit of the results of the tests. Such interdiscplinary co-operation brought together the three areas of textual evidence, history of metallurgy and numismatics. The information in the historical texts was applied in the identification of the alloys, and the results of the tests were, in turn, applied back to the historical texts. The evidence was then examined from the perspectives of the history of metallurgy, the history of money, as well as numismatics. In testing the results of the metallurgical analysis against different disciplines, the results were themselves tested. This interdisclipinary approach has added immensely to their validity.

A new approach: combining old and new ways

The traditional way of appraising coins was essentially 'by eye', and involved no small amount of experience of handling genuine pieces along with a gradual accumulation of expert knowledge. Critical aspects included form, inscription, calligraphy, decoration, size, weight and patterns of corrosion. It was, in effect, an appraisal based on the external factors of the coin. There was no way of investigating the internal factors of the coin beyond surface level. Now, by applying new scientific methods, we can confirm both the external factors of a coin and its internal composition. By means of physical and chemical analysis we can determine the alloy composition of coins of different periods of history and of different forms, and by comparing the results we can trace the development of the metal alloys used in coin production through the ages. We can also pinpoint significant changes at different periods and in different locations. This adds an entirely new dimension to the identification and appraisal of coins. Not only does it open up a new field of study, thereby enriching the field of numismatics, it also helps us to gain a more comprehensive and more accurate understanding of ancient coins, as well as providing a new stimulus for further research.

Of course, it is important both to continue to maintain the traditional ways and to bring together the traditional and modern scientific methods. Both are necessary and complementary, as one method cannot provide all the information offered by the other. In short, it is essential for scientists and numismatists to work together for a fuller and more accurate understanding.

Notes

1 Nippon Kyoto Teikoku Daigaku (Tokyo Imperial University), *Suiyo Kaishi*, vol.1, no. 8 (1911).
2 Wang Jin *et al.*, *Zhongguo Gudai Jinshu Huaxue ji Jin Danshu*, Shanghai: Zhongguo kexue tushu yiqi gongsi, 1995, 21–38.
3 Wang Jin *et al.*, *Zhongguo Gudai Jinshu Huaxue*, 39–51.
4 Michino Shokaku, 'Kodai shina kahei no kagaku kenkyu', (in 2 parts), *Nihon Kakagu Kaishi* vol. 51 (1930), 463–73 and vol. 53 (1931), 100–9.
5 Kato Shigeshi (trans. by Wu Jie), *Zhongguo Jingji Shi Kaozheng*, Beijing: Shangwu shuguan, 1959, juan 1, 147–55.
6 Wu Chengluo, 'Zhongguo gu qian fenxi jieguo', *Huaxue Gongye* vol. 4, no. 2 (1929), 127–28. Shen Xiongqing, 'Zhongguo zhiqian zhi dingliang fenxi', *Huaxue Gongye* vol. 5, no. 1, 117–18.
7 Wang Jin and Yang Guoliang, 'Zhongguo gudai tong hejin huaxue chengfen bianqian zouxiang de yi ban', *Hangzhou Daxue Xuebao* 1959(5), 43–50. Wang Jin, 'Cong Ming Qing liang dai zhiqian huaxue chengfen de yanjiu tan zai gai shiqi zhong youse jinshu yelian jishu zai Zhongguo fazhan qingxing de yi ban', *Hangzhou Daxue Xuebao* 1959(5), 51–61.
8 Mizuno Masakatsu, 'Shinorishutsudo kosen kinzoku sosei', in Ichiritsu Hakodate hakubutsukan (Hakodate Municipal Museum) and Hakodate kyoiku i-inkai (Hakodate Education Committee), *Hakodate Shinori Kosen*, 1973. Mabuchi Hisao *et al.*, 'Toho kosen genshi kyushu koufuhou kagaku kenkyu', *Kyubunkazai no Kagaku*, vol. 22, juan 20 (1978), 20–23. Mabuchi Hisao *et al.*, 'Kodai kahei kagaku soshiki', *Nihon Kagaku kaishi* 1979(5), 586–90.
9 Dai Zhiqiang, 'Bei Song tongqian jinshu chengfen chutan', *Zhongguo Qianbi* 1985(3), 7–16. Zhao Kuanghua, Hua Jueming *et al.*, 'Bei Song tongqian huaxue chengfen pouxi ji jia-xi-qian chutan', *Ziran Kexue Shi Yanjiu* vol. 5, no. 3 (1986), 229–346. Zhao Kuanghua, Hua Jueming *et al.*, 'Nan Song tongqian huaxue chengfen pouxi ji Songdai dantong zhiliang yanjiu', *Ziran Kexue Shi Yanjiu* vol. 5, no. 4 (1986), 321–30.
10 Zhou Weirong's M.Sc. thesis 'Mingdai tongqian chengfen pouxi ji Mingdai huangtong yu jinshu xin yelian de lishi tantao', July 1987. Zhou Weirong, Zhao Kuanghua *et al.*, 'Mingdai tongqian huaxue chengfen pouxi', *Ziran Kexue Shi Yanjiu* vol. 7, no. 1 (1988), 54–65. Zhou Weirong, 'Woguo gudai huangtong zhuqian kaolüe', *Wenwu Chunqiu* 1992(2), 18–24. Zhou Weirong, 'Shui xi kao bian', *Wenwu Chunqiu* 1992(3), 57–61. Zhou Weirong and Fan Xiangxi, 'Zhongguo gudai huangtong zhuqian licheng yanjiu', in Zhao Lingyang and Feng Jinrong (eds) *Yazhou Keji yu Wenming* (Mingbao chubanshe, 1995). Zhou Weirong, 'Huangtong yezhu jishu zai Zhongguo de chansheng yu fazhan', *Gugong Xueshu Jikan* vol. 18, no. 1 (2000), 67–92.

Postscript by Dai Zhiqiang

In November 2002 a Metallurgy and Numismatics Conference was held in China. It celebrated the revolution that has been taking place in modern Chinese numismatics, bringing together numismatists and scientists.[1] The results of this co-operation have been phenomenal.

Although there has been close co-operation between the fields of metallurgy and numismatics in the West for over 100 years, it has taken much longer for such co-operation to become established in China. The earliest attempts took place in China in the 1920s, but numismatists did not embrace the results and scientists perhaps did not realise the vast reservoir of data that the coins could offer.

In September 1982, the Henan Archaeological Society organised a conference looking at Metals in Archaeology. As I was working in Anyang, Henan, at the time, and was Head of the China Numismatic Society, I prepared a paper on the metal content of Chinese coins. For reasons of convenience, I started with a group of Northern Song coins, asked Wang Tihong at the Luoyang Copper Works to analyse samples from the coins, and then wrote up the results.[2] The results were encouraging and showed how scientists could contribute to numismatics. It happened that Hua Jueming, Deputy Head of the History of Natural Sciences Research Centre, Chinese Academy of Sciences, and Professor Zhao Kuanghua of the Chemistry Department, Beijing University, were also beginnning to explore and analyse Chinese coins. In summer 1985 they set up a working group at the Centre to facilitate co-operation with colleagues working in antiquities and numismatics. In early 1986, I met with Hua Jueming at the State Bureau of Cultural Relics to discuss how we could develop a project looking at the alloy composition of Chinese coins. Since then, Zhao Kuanghua, Hua Jueming and I have worked closely together.

Hua Jueming retired in 1993, and in order to continue our co-operation, his assistant, Zhou Weirong (who was then a research student under Zhao Kuanghua) was transferred to the China Numismatic Museum. Since then, Zhou Weirong and I have worked together to develop metallurgy in numismatics as an increasingly stronger branch of study. As Director of the Museum, much of my time has been occupied with administrative matters. Zhou Weirong's efforts have ensured that our collaboration has continued to fruition, and his hard work has been recognised in his promotion: in 1995 to Deputy Research Fellow, in 2000 to Research Fellow, and in 2001 he was selected by the State Council's Academic Committee as a Member of the Specialist Team on the History of Science and Technology.

This book brings together reliable and scientific data collected from over 2,000 coins, from the pre-Qin period down to the late Qing dynasty. It is important first-hand evidence for the study of coins, in particular the evolution and development of the alloys used in coin production. The specimen coins were carefully selected, mostly from excavation, though with a small number of coins from collections. Samples were taken and tested with care, with Zhou Weirong always present. The methods used were the chemical quantitative method and the classical chemical method. Occasionally other methods were used, and these are noted where appropriate in the book. The coins were then examined again, in the light of the scientific data. Where questions arose, the coins were retested. The process was constantly being improved. In the early stages, we had overlooked the need to take photographs or rubbings of the coins, so we corrected this oversight. At first, we tested only the main elements of the alloy, but after discussions with colleagues overseas, we realised the importance of testing the minor elements as well, as they also offer evidence relating to the date, mints, mines and sources of metals, as well as the technology used to manufacture the coins. In short, the minor elements are there for a reason.

This book brings together the data from the analysis and illustrations, but it goes much further than that in its interpretation of the results. It reveals the alloy composition of Chinese coins through the ages, and the characteristics of particular periods. It also offers a chronological survey of the development of metal alloys in China.

Notes

1 Dai Zhiqiang, 'Qianbixue he jinshu yezhu shi', *Zhongguo Qianbi* 2003(1), 5–7.

2 Dai Zhiqiang and Wang Tihong, 'Bei Song tongqian jinshu chengfen shixi', *Zhongguo Qianbi* 1985(3), 7–16. [First published, with restricted circulation, in Henan in 1984.]

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